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Aeronautical Engineering REVIEW

October, 1955

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Aeronautical Engineering Review

Vol. 14—No. 10 October, 1955

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Cover—IAS-RAeS Fifth International Aeronautical Conference Dinner, June 23, 1955, Hollywood, Calif. (Complete story of the Conference begins on page 40.)

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I.A.S. News Notes

October 1955

WRIGHT BROTHERS LECTURE

Raymond L. Bisplinghoff, Professor of Aeronautical Engineering at Massachusetts Institute of Technology, has been chosen to deliver the Wright Brothers Lecture December 17. His topic will be: "Some Structural and Aeroelastic Considerations of High-Speed Flight."

* * * * *

TULSA SECTION ORGANIZED

A new Section of the IAS has been formed in Tulsa, Okla., with 37 charter members. Clark L. Marks was elected Chairman at the organization meeting August 23. Tulsa becomes the Institute's twenty-fifth Section.

* * * * *

THE GIANNINI FILM LIST

The second edition of The Giannini Film List has been published by the IAS, and may be obtained by writing IAS Headquarters in New York. The catalog describes about 170 unclassified, released aeronautical films that may be borrowed by IAS Sections and Student Branches from various sources such as the Air Force, Navy, NACA, and aircraft companies. It is published under auspices of the Giannini Film Library Fund.

* * * * *

IAS THESIS TOPICS LIST

A list of suggested thesis topics for student engineers and scientists has been compiled by the IAS for distribution to all Student Branches, Faculty Advisers, and Corporate Members. The booklet contains about 800 topics, suggested by Corporate Members, based on currently unsolved aeronautical problems that the aircraft industry considers worthy of the student's investigation. Copies available on request.

* * * * *

NATIONAL MEETINGS CALENDAR

Nov. 3-4	Joint Meeting of the Canadian Aeronautical Institute and the IAS, Chateau Laurier, Ottawa, Ontario, Canada.
Dec. 17	Nineteenth Wright Brothers Lecture, U. S. Chamber of Commerce Building Auditorium, Washington, D. C.
Dec. 20	Wright Brothers Lecture (Repeated), IAS Building, Los Angeles.
Dec. 22	Wright Brothers Lecture (Repeated), Lewis Flight Propulsion Laboratory, NACA, Cleveland.
Jan. 23-26	Twenty-Fourth Annual Meeting and Honors Night Dinner, Sheraton-Astor Hotel, New York.
March 9	Flight Propulsion Meeting (Confidential), Hotel Carter, Cleveland.
June 18-20	Summer Meeting, IAS Building, Los Angeles.

* * * * *

I.A.S. News Notes (con't.)

SECTION MEETINGS CALENDAR

Oct. 8 New York Section: Field Trip to Experimental Towing Tank at Stevens Institute of Tech., Hoboken, N. J. Lunch 1 p. m. Inspection Tour 2 p. m.

Oct. 11 Los Angeles Section: Specialist Meeting at IAS Building, 8 p. m. "Recent Developments in Rarefied Gas Flows" by Lester Lees, Professor of Aeronautics, California Institute of Technology.

Oct. 11 San Diego Section: Meeting at IAS Building, 8 p. m. "C-131C Turboprop Experience" by Colonel Smith.

Oct. 11 Tulsa Section: Meeting at Phillips Engineering Building (Room 101), Tulsa University, 7:30 p. m. Election of officers.

Oct. 11 Washington Section: Meeting at Occidental Restaurant, 8 p. m. "Air Force Calls Industry from the Bench; or, Activating the Air Force-Industry R&D Team" by Colonel Taylor Brysdale, USAF, Directorate of Development, ARDC.

Oct. 12 Niagara Frontier Section: Meeting at Airways Hotel, Buffalo Municipal Airport. Social Hour 7:30 p. m., Meeting 8 p. m. "The Vickers Viscount" by Hugh F. Jacox, Assistant Sales Promotion Manager, Capital Airlines, Inc.

Oct. 17 Indianapolis Section: Dinner Meeting at 1435 West Morris St. Social Hour 6 p. m., Dinner 7 p. m., Meeting 8 p. m. "Weapons Systems for Supersonic Aircraft" by W. C. Keller, Assistant to the Chief Engineer, Convair, A Division of General Dynamics Corporation.

Oct. 18 Cleveland-Akron Section: Dinner Meeting at Sleepy Hollow Golf Club. Social Hour 6 p. m., Dinner 7 p. m., Meeting 8 p. m. "Some Principles of Missile Guidance" by Col. Richard C. Gibson, USAF, Deputy Chief, Guidance and Control Division, ARDC. At 4 p. m. there will be a tour of the B. F. Goodrich Research Laboratory in Brecksville, Ohio.

Oct. 18 Hampton Roads Section: Meeting at NACA Administration Building, Langley AFB, 8 p. m. "Supersonic Propulsion Systems" by Abe Silverstein, Associate Director of Lewis Flight Propulsion Lab., NACA.

Oct. 20 Los Angeles Section: Confidential Meeting at IAS Building. Social Hour 6 p. m., Dinner 7 p. m., Meeting 8:30 p. m. "Development History of the F-100" by L. P. Greene, Aerodynamics Group Leader, North American Aviation, Inc.

Oct. 20 Twin Cities Section: Meeting at Northwest Airlines. Inspection of Navigation and Communication Equipment under guidance of Blake Cahill, NWA Engineering Pilot.

Oct. 26 St. Louis Section: Confidential Meeting at the Engineers Club, 8 p. m. Panel discussion on "Flying Qualities of Jet Fighters" led by R. C. Little, McDonnell's Chief Test Pilot; Major Kit Murray, USAF Research Pilot, Edwards AFB; Bob Champine, NACA Research Pilot, Langley Lab.; and Major Jim Butler, WADC (Moderator.)

Nov. 2 Philadelphia Section: Joint Meeting with The Franklin Institute, at Franklin Institute. "The Role of the Strategic Air Command" by Brig. Gen. R. M. Montgomery of SAC Headquarters, Omaha, Neb.

Nov. 9 Dayton Section: Dinner Meeting at Miami Hotel. Social Hour 6 p. m., Dinner 7 p. m. Talk by Brig. Gen. Thomas L. Bryan, Jr., USAF, Commander, WADC.

* * * * *

IAS News

A Record of People and Events of Interest to Institute Members

CAI-IAS Joint Meeting

Second Annual Conference in Ottawa November 3 and 4 Will Include Tour of NAE Laboratory

THE SECOND JOINT MEETING of the Canadian Aeronautical Institute and the Institute of the Aeronautical Sciences will be held November 3 and 4 in Ottawa, Ont., Canada. The Chateau Laurier will be headquarters for the annual event.

The 2-day program will consist of three technical sessions, a dinner, a tour of the National Aeronautical Establishment, and the inaugural W. Rupert Turnbull Memorial Lecture. The dinner speaker will be the Rt. Hon. C. D. Howe, Canadian Minister of Trade and Commerce, who won the Daniel Guggenheim Medal last year. John H. Parkin, Director of the National Aeronautical Establishment, has been chosen to deliver the Turnbull Lecture.

Nine papers will be presented, five by American authors and four by Canadians. Subjects to be covered are (1) Aircraft Structures, (2) Materials and Processes, and (3) Aircraft Safety Design and Accidents. An outline of the program follows.

▸ **Thursday morning**—Session on Aircraft Structures, with B. J. Kaganov, Chief Structures Engineer of Canadair Limited, as Chairman. "Unique Structural Problems in Supersonic Aircraft Design" by Fred P. Mitchell, Chief Stress Engineer, Avro Aircraft Limited; "Optimum Structural Design of Wing Box Beams" by Saul Bernstein, Group Leader, Stress Department, Canadair Limited; and "Experiment and Theory in Investigating the Behavior of Structures at High Temperatures" by Nicholas J. Hoff, Head of Department of Aeronautical Engineering and Applied Mechanics, Polytechnic Institute of Brooklyn.

▸ **Thursday afternoon**—Turnbull Lecture. In this first memorial lecture, entitled "W. Rupert Turnbull, 1870–1954," Mr. Parkin will review the pioneering work of the noted Canadian aeronautical engineer in a technical-historical light. Mr. Turnbull, an Honorary Fellow of the CAI, constructed a wind tunnel and began experiments on wing shapes in 1902. Later turning his attention to propeller theory, he won the Royal Aeronautical Society's Bronze Medal in 1911 and developed an electrically controlled variable-pitch propeller that was flight tested successfully in 1927.

A prepared discussion will follow the lecture. The Chairman will be T. E. Stephenson, Director of the Aircraft Branch, Department of Defence Production, Canada.

▸ **Thursday evening**—Dinner at 7:00 p.m. in the hotel ballroom, preceded by a small reception for the guests of honor. Mr. Howe will be introduced by R. D. Richmond, CAI President.

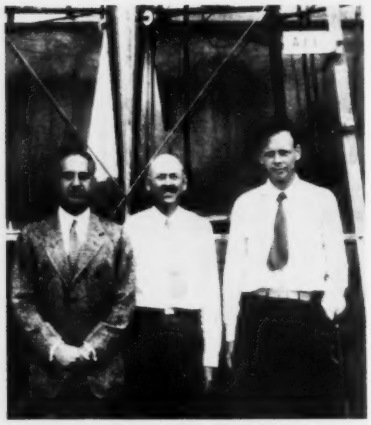
▸ **Friday morning**—Session on Materials and Processes, with H. L. Eberts, President of Fleet Manufacturing Limited, as Chairman. "Aluminum Alloys for Elevated-Temperature Service" by Edgar H. Dix, Jr., Assistant Director of Research, Aluminum Company of America; "Materials and Fabrication Techniques for Structural Heat-Resistant Plastic Sandwiches" by Norman E. Wahl, Head of Plastics Section, Materials Department, Cornell Aeronautical Laboratory, Inc.; and "The Metal Bonding of Assemblies for the Canadair CL-28 Maritime Reconnaissance Airplane" by Jason J. Waller, Chief Materials and Process Engineer, Canadair Limited.

Session on Aircraft Safety Design and Accidents, with I. A. Gray, Director of Maintenance and Engineering, Canadian Pacific Air Lines, as Chairman. "Aircraft Accident Investigation Techniques" by Group Capt. Ralph C. Davis, Director of Flight Safety, RCAF; "Significant Problems in Air Safety" by Jerome Lederer, Managing Director, Flight Safety Foundation, Inc., and Director of the Cornell-Guggenheim Aviation Safety Center; and "Recent Results of the NACA Crash-Fire Research with Jet Airplanes" by I. Irving Pinkel, Associate Chief of the Physics Division, Lewis Flight Propulsion Laboratory, National Advisory Committee for Aeronautics.

R. D. Richmond
President, CAI

▸ **Friday afternoon**—Tour of the Structures, High-Speed Aerodynamics, Gas Dynamics, and Engine Laboratories at the National Aeronautical Establishment, Montreal Road, Ottawa. There will be an opportunity to visit the Hydraulic and Ships Laboratory, chiefly for the purpose of seeing a model of the St. Lawrence Seaway, an interesting non-aeronautical diversion. Delegates who are not citizens of the United States or of Canada must obtain security clearance in advance from the NAE.

Everett B. Schaefer heads the Program Committee for this second annual meeting of the CAI and IAS. Copies of the program have been mailed to the members of both societies.



Harry F. Guggenheim, Robert H. Goddard, and Charles A. Lindbergh *(left to right)* pictured beside Goddard's rocket launcher near Roswell, N.M., during a series of high-altitude rocket shots made in the mid-Thirties.

Tribute to R. H. Goddard

Three aviation leaders marked the tenth anniversary of the death of Robert H. Goddard, AFIAS, with a tribute describing the rocket and jet propulsion pioneer as "the almost forgotten man behind today's international developments in long-range rockets, earth satellites, and space flight."

James H. Doolittle, IAS Past-President and Honorary Fellow; Harry F. Guggenheim, MIAS, and Charles A. Lindbergh, FIAS, joined in a statement issued to the press through The Daniel and Florence Guggenheim Foundation.

They cited Goddard, who died on August 10, 1945, as the "founder of a whole new field of engineering which now has grown into a billion-dollar industry."

Listing a number of "firsts," they said he "developed during the 1930's large and successful rockets which anticipated many features of the German V-2 rockets, including gyroscopic control, steering by means of vanes in the jet stream of the rocket motor, power-driven fuel pumps, and other devices."

Goddard was credited with developing the first liquid-fuel rocket, proving by actual test that a rocket would work in a vacuum, and developing the basic idea of the bazooka long before it was put to use. He began his research in 1912 and was directing Navy rocket investigations at the time of his death.

Arma Division Joins IAS

Arma Division of American Bosch Arma Corporation has joined the IAS as a Corporate Member. Located at Roosevelt Field, Garden City, Long Island, N.Y., Arma is engaged primarily in the design, development, and manufacture of air-borne navigational and control systems for the military. About three-fourths of its current work load is in bomber defense systems, missile guidance, integrated navigation and fire control systems, and other air-borne instrumentation.

Arma owes its advanced position in the industry, officials say, to its development and production of defensive systems for the nation's newest intercontinental long-range bombers; to its great progress in inertial navigation; and to 37 years of pioneering experience in precise instrument systems for navigation, fire control, and computation.

The company has shown ability to develop and reduce to mechanized quantity production a complete line of small, accurate, interchangeable instrument components from which air-borne systems can be assembled for an endless variety of purposes.

Of particular importance is a subminiature gyroscope with the dependable accuracy required for missile guidance. This was developed for stabilization purposes in self-contained or inertial navigation systems in which all-weather effectiveness, complete silence, and freedom from enemy interference are accomplished by elimination of magnetic, optical, radio, radar, and all other contact with the earth and stars.

The tiny gyroscope is used in the Arma Subminiature Gyro Compass, which is smaller than a $10^1/_2$-in. cube yet said to be as accurate as much larger and heavier fire-control compasses.

New Corporate Member

Engineering Supervision Company, of 743 Fifth Ave., New York City, has joined the IAS as a Corporate Member. Licensed by the State of New York to provide consulting engineering services, its activities cover the design and supply of heavy industrial equipment to specifications drawn up to meet the particular needs of client companies. Engineering Supervision Company accepts assignments for research and development of manufacturing methods and processes, design of complete plants, engineering of turnkey jobs, and automation of existing or contemplated facilities.

The company also conducts engineering and management surveys for its clients. Among other fields, its activities cover plastic forming of metals (rolling mills, hydraulic and mechanical presses, roll forming, deep drawing, forging, extrusion), metal fabricating plants, power plants, and mechanical processing plants.

Educational Leaders Chosen

Four IAS members head the Aeronautical Division of the American Society for Engineering Education. The new officers, elected at the ASEE's annual meeting last June at The Pennsyl-

Scale model of the Domier Do.S Flying Boat has been given to the IAS by The Garrett Corporation's AiResearch Manufacturing Division. Made in Germany of chrome-plated sheet brass, the model shows virtually every detail of Germany's huge all-metal seaplane that flew across the Atlantic in the early 1930's. E. W. Robischon *(left)*, Western Region Manager of the IAS, and Claude Monson, Vice-President and Plant Manager of AiResearch, are shown examining the model.

vania State University, are: Chairman —John W. Hoover, Associate Professor of Aeronautical Engineering, University of Florida; Vice-Chairman—John M. Coan, Professor of Aeronautical Engineering, University of Illinois; Secretary—E. W. Anderson, Professor of Aeronautical Engineering and Mathematics, Iowa State College; and Council Representative—David J. Peery, Professor of Aeronautical Engineering, University of Michigan.

Trophy for Soaring Flight

The Larissa Stroukoff Foundation, an education and welfare trust established by Michael Stroukoff, AFIAS, Chief Engineer of Stroukoff Aircraft Corporation, has announced the gift of a silver trophy and a fund of $5,000 to the Soaring Society of America. The trophy, with a certificate and a cash prize, will be awarded annually to the winner of the goal-and-return flight at the National Soaring Contest in Elmira, N.Y.

Steve Bennis, of Linthicums Heights, Md., won the 1955 trophy on July 13 with a flight of 136 miles.

NEWS OF MEMBERS

▸ **Don R. Berlin** (F), President and Chairman of Piasecki Helicopter Corporation, has been honored by the American Volunteer Group (Flying Tigers) for his work in developing the P-40 when he was Chief Engineer of the Curtiss-Wright Airplane Division 15 years ago. Major Gen. Claire Chennault, USAF (Ret.), who led the Flying Tigers in China, presented him with the honorary insignia of the AVG at a reunion banquet of the Fourteenth Air Force Association.

▸ **August C. Esenwein** (M), a Vice-President of Convair, A Division of General Dynamics Corporation, and manager of the company's Fort Worth plant, has been presented a 5-year service emblem.

▸ **William F. Gibbs** (AF), President of Gibbs & Cox, Inc., naval architects, has been chosen to receive the Elmer A. Sperry Award November 17 at the Annual Meeting of the American Society of Mechanical Engineers.

Ralph S. Damon, FIAS, President of Trans World Airlines, Inc., has been given the Spirit of St. Louis Medal by the St. Louis Section of ASME for "meritorious service in the field of aeronautics."

▸ **Charles J. McCarthy** (F), Board Chairman of Chance Vought Aircraft, Inc., has been appointed to the National Defense Committee of the U.S. Chamber of Commerce.

▸ **C. R. Smith** (AM), President of American Airlines, Inc., has been named to the National Defense Committee of the U.S. Chamber of Commerce.

(*Continued on page 92*)

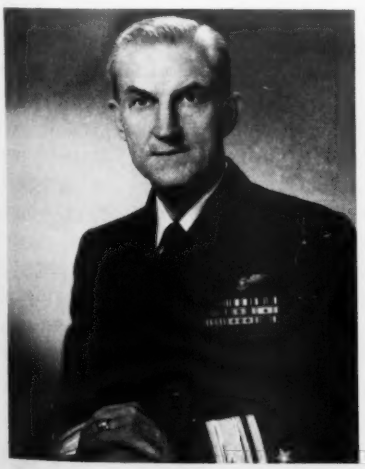
William C. Heath, AFIAS, Executive Engineer—Marketing, Solar Aircraft Co., has been elected Chairman of the San Diego Section of ASME. He previously headed the San Diego Sections of the IAS and SAE.

Necrology

Rear Adm. Apollo Soucek

Rear Admiral Apollo Soucek, HMIAS, who was Chief of the Bureau of Aeronautics when he retired from the Navy in June, died July 22 in Washington, D.C., at the age of 58. Burial was in Arlington National Cemetery.

Born in Lamont, Okla., February 24, 1897, Soucek was graduated from the U. S. Naval Academy in 1921. Three years later he won his wings as a naval aviator at Pensacola NAS. In 1929 Lieutenant Soucek set an altitude record of 39,140 ft., flying a Wright "Apache," and the following year he climbed to 43,166 ft. for a new world's record.



His high-altitude flights called attention to such problems as near-hurricane winds and −60° temperatures at 40,000 ft., the frosting of goggles, and the need for better oxygen equipment for the pilot and a supercharger for the engine.

During World War II, Admiral Soucek served as Air Officer and Executive Officer aboard the aircraft carrier U.S.S. "Hornet." He later commanded the carrier U.S.S. "Franklin D. Roosevelt."

In 1947–1949 Admiral Soucek was Commander of the Naval Air Test Center at Patuxent, Md., and he later became Assistant Chief of Naval Operations for Aviation Planning. In 1952 he commanded Task Force 77 in Korean waters. His honors included the Distinguished Flying Cross and the Silver Star Medal.

for the IAS—

It is particularly pleasant for me to find myself the President of the Institute in a year when we have this fine visit by so many of our colleagues from England.

Not being an engineer by profession, I am very envious of the talents you men have, and so, perhaps it is appropriate for me to say a few words about a profession of which I have learned a good deal in my last 25 or 30 years working in this business. I have come to feel that engineering capability is the most precious element in the whole aeronautical apparatus, and the mastery of the air is being recognized more and more as the trump card at the conference table for world peace. Surely, this must make you conscious of your responsibility and also of your great opportunities.

These engineering capabilities are rare and hard-to-come-by attributes. We do not create these talents by forced draft methods. No amount of money or urgency will make an engineer overnight out of a raw man. He has to develop himself. To do the great work ahead of us in aeronautical research, we cannot build a mecca and merely whistle through our fingers and have a whole

for the RAeS—

Thank you, Mr. President, for the very kind way you introduced me, and thank you, also, for permitting me to be the last speaker. As a stranger in a strange land, I would not like to be put in, as you would say it in England, fat first. It is a little bit nerve-shattering, and I was very glad to know I was to be the third speaker and not the first.

It is a very great privilege to have the honor of being one of the speakers in the opening of the Fifth Annual American Aeronautical Conference. It is a great privilege because I think these conferences are very deeply significant of some of the most important facets of our work, not only as engineers and scientists in our own countries but in relation to what goes on in wider fields.

Firstly, perhaps, these conferences are a great tribute to the wonderful spirit of association which has always distinguished the meetings between our two Associations—yours a young and vigorous and virile aeronautical body and ours with its roots rather deep in history

Fifth

new complement of engineers at our gates just when we need them.

I know there is a great deal to be done to persuade young men that aeronautical work has a great future and is promising. There is still much to be done to train them slowly and surely. We must resign ourselves, I think, to the fact that we are not going to get many more new engineers now and that, therefore, we must make better utilization of the distinguished profession that you men represent.

I strongly suspect that there are rich returns indeed to be had by a better utilization of the present engineering population and that you, Mr. Rowe, and our British colleagues can tell us much and help us greatly in this direction. I hope that before you return we shall glean some words of wisdom from you in this area. Somehow I have the feeling, if we could get a better, simpler, and different approach to developing new types of planes, we might astound ourselves and our military and naval friends, too, as to what we could do with the people we now have.

All this makes me think that the papers and data you will exchange with us here this week will be important and of great interest. But the greatest asset that can emerge from the engineering crucible is not just the papers, but the exchange of human and personal ideas. Most of the papers to be presented this week are already written and printed. They could be mailed around to everyone. In a strictly intellectual sense we could do just some of the things we are now proposing to do by merely mailing letters across the ocean. In a deeper sense, however, a meeting like this accomplishes purposes that could be achieved in no other way than by bringing people together, face to face.

Probably there is no more material thing or more essential ingredient in world peace than world understanding. I think that today the airplane is building this world understanding, this world community (quite apart from all the things that governments can do), because it carries not just the leaders but also the little people. After all, down through the years, they are the ones who by better understanding and by allaying suspicions will, in the final analysis, determine the shape of things to come.

So, it is to you scientists and aeronautical engineers of the mid-Twentieth Century who can lay the basis for future world peace and understanding that I extend my personal and my official welcome at this time.

ROBERT E. GROSS
President, IAS

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but, I hope, still retaining some of the vigor that distinguishes your great industry.

This spirit of association is one of the important things of life, and it, perhaps, is also reflected in the way in which our two countries have steadily moved closer together in this great field of aeronautics and moved more closely together because success in aeronautics is the key to peace. It is the great weapon which will win peace for us. If peace is preserved, then aeronautics can go forward and garner the fruits by way of our transport and other means in which it can revolutionize the surface of things more rapidly than any other power we have today.

That is the significance of these conferences. It represents so much for us. To come down perhaps to more homely things, I would like to touch also on a point made by your President. These conferences have been great meeting grounds for people with common interests. When aeronautical people get together, there is always a tremendous stimulus of thought. They are dealing with pioneering matters, and they get together and find friendships. It is in the renewing of friendships and in the creating of new friendships that these conferences play one of their greatest parts.

Your own President, of course, told you the value of the papers and discussions and, perhaps even more, the tremendous value of these more intimate discussions that go on and make these conferences of very great value.

I would just like to mention that we tried to support the conference. I think we have a good delegation over here. The numbers, I think, are reasonable. I would like to say we have our three vice-presidents here, one of them only elected about a week ago, so that I feel that we are well represented, which is extremely important to give these things their true value. I hope that out of the scope and range of the papers, which cover practically the whole range of aeronautical transport, we will get discussions which will be of very great value.

Your President has welcomed you here. Time is running on. I think all I have to say now is to wish us all a very happy conference and a successful outcome to our papers, our meetings, and especially our friendships.

N. E. ROWE
President, RAeS

Conference Amenities

A Diary of the Fifth International

by
Welman A. Shrader

The Hollywood-Roosevelt Hotel, with its inviting swimming pool *(top)*, and the Institute's Los Angeles building *(center)* are headquarters for the Conference. Registration desks, set up in the foyer of the IAS building, are shown in the bottom photo.

Introduction

FOR THE FIFTH TIME since 1947, the Royal Aeronautical Society and the IAS staged an international conference that brought together many of the top aviation people of Europe and the North American Continent. Official delegates of Great Britain and the United States were in the majority, but representatives from Australia, Canada, France, Holland, Norway, and Switzerland also participated in this year's meetings. (A complete list of the RAeS delegates is carried on page 60.)

Los Angeles, the Hollywood-Roosevelt Hotel, and the Institute's western building, served as headquarters for this fifth joint conference. Much credit for the success of a full and interesting program goes to the Institute's West Coast Sections and to the diversified aircraft industries of the State of California. Even the local Chambers of Commerce and the weathermen cooperated to provide ideal conditions for the entire 2 weeks of business and social activities.

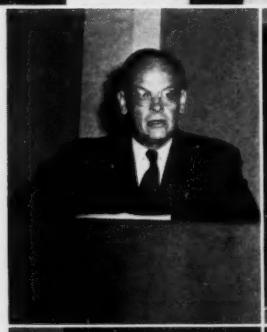
As usual, this conference was planned to encompass three major courses of interest and value—technical sessions, visits to aircraft industry facilities, and a program of social events that included the ladies of the visiting delegates.

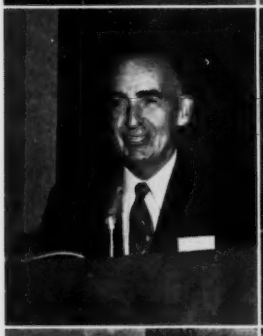
Since the timing coincided with the Institute's usual West Coast summer meeting, the technical sessions of this conference took the place of that annual affair. American IAS members attended the 3 days of technical sessions, then had a 1-day field trip and an Honors Dinner as usual. The balance of the program was designed specifically for the enlightenment and entertainment of the RAeS visitors, with the West Coast aircraft industry and the Institute's Corporate Member companies acting as hosts.

Aeronautical Conference

June 20—July 1, 1955, California, U.S.A.

Familiar scenes around the Institute building during the Conference include: *(top left)* crowds around the mail and message desk; *(top right)* delegates relaxing or holding private discussions in the building's lounge; *(bottom left)* lunching in the outdoor tent adjoining the auditorium; *(bottom right)* the mid-morning coffee break; and *(center)* the fleet of modern, air-conditioned busses used to transport visiting delegates.





IAS Director S. Paul Johnston opens the proceedings of the Fifth Joint Conference and introduces the principals of both societies. Pictured below and on the opposite page are the American and British joint-chairmen of the technical sessions in the order of their appearance and listing in the text below.

June 20, 21, and 22

▸ **Opening Reception**—Except for an informal reception on the evening of June 20, the first 3 days and nights of the conference were devoted entirely to technical sessions. The opening reception, held in the Aviation Room of the Hollywood-Roosevelt, was given by the Officers and Council of the Institute to welcome the British delegates and their wives. Approximately 250 people, including local IAS committee members and officers and their wives, attended.

▸ **Technical Sessions**—Officially, the Fifth International Aeronautical Conference got under way at 10:00 a.m. on the morning of the 20th, with welcoming remarks by the presidents of the two societies. Excerpts of the addresses by Messrs. Gross and Rowe are to be found on pages 38, 39.

A total of 18 papers—9 British, 8 American, and 1 Canadian—were presented during the 3 days of June 20-22. Evening sessions, featuring one paper at each, were held on Tuesday and Wednesday nights.

Each of the eight technical sessions was presided over jointly by two chairmen—one British and one American. Although this represented a slight departure from the procedure of past conferences, it proved extremely advantageous in the stimulation of discussions by members of both societies. Those who served as joint chairmen of these sessions were:

Monday Morning—A. E. Raymond, Vice-President—Engineering, Douglas Aircraft Company, Inc.; and S. Scott-Hall, Head of Ministry of Supply Staff, British Joint Services Mission.

Monday Afternoon—C. J. McCarthy, Chairman, Board of Directors, Chance Vought Aircraft, Inc.; and R. L. Lickley, Chief Engineer, Fairey Aviation Company, Ltd.

Tuesday Morning—H. L. Dryden, Director, National Advisory Committee for Aeronautics; and Sir Arnold Hall, Director, Royal Aircraft Establishment.

Tuesday Afternoon—Clark B. Millikan, Director, Guggenheim Aeronautical Laboratory, California Institute of Technology; and E. T. Jones, Principal Director, Scientific Research (Air), Ministry of Supply.

Tuesday Evening—Hall L. Hibbard, Vice-President—Engineering, Lockheed Aircraft Corporation; and G. R. Edwards, Managing Director, Vickers-Armstrongs, Ltd.

Wednesday Morning—P. R. Bassett, Vice-President, Sperry Rand Corporation; and Sir A. H. Roy Fedden, Past-President, Royal Aeronautical Society, Aeronautical Consultant.

Wednesday Afternoon—L. B. Richardson, Senior Vice-President, General Dynamics Corporation; and Air Commodore F. R. Banks, Director, Bristol Aeroplane Company.

Wednesday Evening—T. P. Wright, Vice-President for Research, Cornell University; and Hayne Constant, Director, National Gas Turbine Establishment.

All of the 18 papers presented were available in preprint form at the opening of the meeting. This, in itself, represented a unique achievement in the annals of these conferences and reflects a great deal of credit on the authors from both societies. The availability of papers went a long way toward the stimulation of more profuse and constructive discussions.

▸ **Proceedings**—The complete papers, together with discussions, will be published later in a bound volume of *Proceedings*. It is expected that these will be available through the Sherman M. Fairchild Publications Fund by the end of the year. Meanwhile, titles and abstracts of papers, in the order of presentation, are as follows:

Operating Experience with Turboprop Aircraft

by Peter G. Masefield

Chief Executive, British European Airways

This paper analyzes British European Airways' commercial experience of nearly a quarter of a million flying hours with Rolls-Royce Dart turboprop engines, since B.E.A. flew its first commercial service with the Vickers Viscount V.630 prototype 5 years ago, on July 29, 1950, between London and Paris.

B.E.A. has now operated 57,000 aircraft hours and $11^1/_2$ million aircraft miles of air-line services with Viscount V.701 turboprop air liners during which some 570,000 passengers have been carried and a net profit of nearly $3,000,000 has been earned.

Mr. Masefield traces the history of the Viscount since its conception in 1945, records B.E.A.'s experience with the Dart turboprop engine in the course of its development to its present status of 1,050 hours between overhaul, and compares in detail its performance, maintenance costs, and reliability with those of equivalent piston engines. He sets out and discusses the economics of the Viscount in B.E.A. service—now running at a profitable, direct operating cost of some $300 a flying hour under European conditions.

The paper goes on to describe the characteristics of the new 65-passenger Viscount Major V.802, due to come into B.E.A. service in 1956. Mr. Masefield discusses pilots' reactions to the operation of turboprop air liners, outlines some special problems encountered, and describes passengers' reactions, which have been encouragingly favorable—especially from Americans.

Looking ahead, he compares the operating characteristics of three similar projected 75-passenger aircraft—one with turbocompound piston engines (350 m.p.h.), one with turboprops (400 m.p.h.), and one with turbojets (500 m.p.h.). He states his belief in the economic superiority of the turboprop vehicle, though he sees a place also for the turbojet in specific "blue-ribbon" operations for the future.

Finally, Mr. Masefield declares his belief that the performance of the Bristol Britannia long-range turboprop air liner will bring it prominently into the world market as a worthy colleague of the Viscount, which is essentially a medium-range airplane.

Mr. Masefield concludes that "the heart of an aeroplane is its engines" and that the success of future turboprop civil transport aircraft is bound up inseparably with the development of such engines as, not only the Dart, but also the Bristol Proteus and BE.25, the Rolls-Royce RB.109, the Napier Eland, the Pratt and Whitney T-34, and the Allison T-56.

"Our experience leads us to believe that these turboprop engines have, within them, inherent characteristics which can make them more attractive to hard-bitten airline operators—equally on the commercial, the flying, and the maintenance sides of the business—than are any other rival types of power unit. They offer a challenge to the airframe manufacturers to wrap around them the most efficient and attractive airframes they can devise—and, in so doing, provide a transport vehicle which can set before the travelling public means of communication substantially in advance of anything available today."

Air-Line Use of Elementary Statistical Methods in Aircraft Performance Measurement

by W. C. Mentzer and F. S. Nowlan

General Manager—Engineering, and Staff Engineer, respectively, United Air Lines, Inc., Maintenance Base, International Airport, San Francisco, Calif.

The paper reviews some of the fundamental differences between an aircraft manufacturer and an aircraft operator pertaining to:

(a) The reasons why each type of organization obtains airplane and power-plant performance data.

(b) The types of performance data desired by each type of organization.

(c) The relative ability of each type of organization to obtain such data, and hence,

(d) The treatment that must be accorded such data and the utility of statistical methods in the case of an operator.

The following subjects are then briefly reviewed to prepare for later discussion of actual analysis of flight-test data:

(a) Statistical distribution functions.
(b) Measures of variability.
(c) Sampling.
(d) Regression and correlation analysis.
(e) Analysis of variance.
(f) Random variation and bias.
(g) Errors and their cumulative effect.
(h) Significance and causality.

The use of these statistical principles is then exemplified by detailed discussion of several flight-test programs involving both power-plant and airplane performance characteristics which have been conducted by United Air Lines.

Design of High-Speed Aircraft

by E. H. Heinemann

Chief Engineer, Douglas Aircraft Company, Inc., El Segundo, Calif.

The development of high-speed aircraft during recent years has presented the aircraft designer with many new problems, since the advent of the jet engine has made it possible to fly in the supersonic as well as the transonic speed range. This paper discusses problems of thrust and drag requirements, stability and control, maneuverability, buffet limit, and thermal limitations.

The distinction is made between the airplane as an air-borne vehicle flying within the earth's atmosphere and thrust-borne vehicles that have ballistic trajectories. It is pointed out that although speed in the upper atmosphere with rocket power plants is practically unlimited, the airplane has some distinct operational limitations.

Also discussed are various recent models of high-performance jet aircraft developed in the author's organization which illustrate how solutions to current problems have been successfully found.

Design of Large Helicopters

by Bartram Kelley

Chief Engineer, Bell Aircraft Corporation, Fort Worth, Tex.

A broad history is presented of the growth of the present-day helicopter rotor, with particular emphasis on disc loading. Power required for hovering flight, tip speed, and average lift coefficient are linked together in a general discussion of rotor parameters. The treatment is not intended exclusively for helicopter technicians but rather for any members of the aircraft industry interested in the broader aspects of preliminary design. The discussion is limited to torque-driven rotors and excludes jet helicopters and convertiplanes. Recent U.S. Air Force-Bell Aircraft flight tests of high subsonic tip speeds are announced for the first time.

Following the discussion of disc loading, lift coefficient, and tip speed, and assuming these quantities to be held constant, elementary formulas are introduced to show the effects of increasing the rotor diameter.

The way in which diameter affects lift, power, torque, blade weight, and centrifugal force leads to a conclusion that there must be an optimum rotor size beyond which further increases are not profitable. For larger helicopters, then, two or more rotors should be used. A comparison is made with the growth of airplane wings, and the helicopter rotor is shown to present a different problem. The old monoplane vs. biplane argument is also ruled out as having no analog in helicopter.

Capacity audiences of more than 600 persons fill the Institute's building auditorium during the 3 days of technical sessions. (A portion of the replica of the original Wright Brothers' airplane may be seen hanging overhead.)

To substantiate the statements on blade weight, seven different Bell Aircraft seesaw rotor designs are algebraically collated in such a way as to bring out the effect of diameter. Data on transmission weights are also included.

Since a maximum practical rotor diameter is believed to exist, a discussion is given of multirotor configurations. Power-required curves are presented for the purpose of comparing single-rotor, tandem, and side-by-side arrangements. The general conclusions are that:

(a) The single-rotor plus tail rotor configuration is best for small helicopters.

(b) The tandem is best for medium or light transports, especially where cruise economy is not important.

(c) The side-by-side configuration is clearly superior for large twin-engined transport types.

In support of the last conclusion there is a presentation of model work carried out at Bell Aircraft on a tailless side-by-side configuration in which the structure between the two rotors consists entirely of a wing-shaped fuselage.

Stress Analysis of Multiweb Boxes

by W. S. Hemp

Professor of Aircraft Structures and Aero-Elasticity, The College of Aeronautics, England

One of the most popular methods of stabilizing the compression skins of the very thin wings of high-speed aircraft consists of the use of a multiplicity of spar webs. This form of construction presents new problems to the stress analyst. The present paper is presented in the hope that it may be of some assistance in resolving these problems. The analysis is confined to the ideal case of a cantilever box of uniform rectangular section, having a single rigid rib at the tip, which receives the external forces. The solutions found are probably representative of the conditions obtaining at the roots of actual wing structures. The fundamental equations are developed in Part I in a form that will allow application to cases where the box is swept back. This generality is introduced in order to show that by the use of an oblique coordinate system an extremely close analogy can be established between the methods of analysis appropriate to the swept and nonswept cases. Detailed solutions for the nonswept case are derived in Part II and are applied in Part III to the analysis of experiments carried out on a test specimen representative of modern practice. The writer is indebted to Messrs. Saunders-Roe Ltd., Isle of Wight, England, for permission to use the results of these experiments.

The Interaction Between Shock Waves and Boundary Layers

by D. W. Holder

Senior Principal Scientific Officer, National Physical Laboratory, England

The interaction between shock waves and boundary layers has important effects in many practical problems, especially when, as a result of the interaction, the boundary layer separates from the surface. This paper reviews the present state of knowledge concerning the fundamental nature of such interactions, gives physical explanations of some of the observed phenomena, and illustrates the importance of the Mach Number, the Reynolds Number, and the strength of the shock wave. Particular attention is given to the flow patterns that are observed when boundary-layer separation occurs near the shock wave and to the conditions that lead to the onset of separation.

Some of the effects of the interaction on the flow round airfoils moving at high-subsonic and transonic

speeds are discussed. It is shown that the occurrence of separation has significant effects on the differential movements of the shock waves on the upper and lower surfaces when the free-stream Mach Number is raised and hence on the loading on the airfoil.

Contributions to Fluid Mechanics from Shock Tube Research

by G. N. Patterson and I. I. Glass

Director and Research Associate, respectively, Institute of Aerophysics, University of Toronto, Canada

The simple theory of the shock tube is based on the assumption that only the three basic wave elements are involved—the rarefaction wave, the contact front, and the shock transition. These waves are represented ideally as an isentropic expansion wave, a contact surface separating two regions of different internal energy, and a discontinuous shock front. Deviations of the real flow in a shock tube from this idealized one-dimensional theory involve variations in the specific heats, effects due to the boundary layer on the rarefaction wave, diffusion effects that cause the contact region to grow with time and relaxation, dissociation, ionization, and bulk viscosity effects on the shock transition.

Experiments in shock tubes have shown that hypersonic flow is accompanied by fundamental changes in molecular structure. It becomes apparent that some effort must be made to calculate the macroscopic (mass) flow of a gas from the motion of its molecules. An outline of the molecular approach to supersonic flows is given in which it appears that supersonic flows may be described as those for which the idealized equation of state ($p = \rho RT$) is valid. It is then shown how one major modification of the molecule (allowance for finite size), consistent with hypersonic flow, is sufficient to introduce a new modified equation of state and the concept of bulk viscosity. The results of this molecular approach are applied to the shock transition problem.

Hypersonic Flow

by Lester Lees

Associate Professor of Aeronautics and Applied Mechanics, California Institute of Technology

This paper discusses some of the areas in which our understanding of hypersonic flows has progressed in recent years, with special reference to the hypersonic-similarity concept and the hypersonic approximations, the interaction between the boundary layer over a slender body and the external inviscid flow, and the flow over blunt bodies, including the heat-transfer problem.

When the inviscid pressure distributions predicted by the hypersonic approximations (Newtonian, shock-expansion, tangent-wedge and cone) are compared with "exact" solutions and experimental data, it becomes evident that this problem is effectively solved for sharp-nosed slender wings and bodies of revolution. The shock-expansion and tangent-wedge (or tangent-cone) method may also be used to construct the flow field. An examination of the equations of motion shows that the simple tangent-wedge (or cone) method, which is thought by some to be largely semiempirical, actually has a sound theoretical basis.

At hypersonic speeds the flow over sharp-nosed slender shapes cannot be properly treated without considering boundary layer-external flow interactions. Since the mass flux through the boundary layer is small, the streamlines entering the boundary layer are nearly parallel to the outer edge. In other words, the flow inclination there is the sum of the body inclination and the slope of the boundary layer, and the local pressure is related to the boundary-layer growth rate by means of the tangent-wedge (or tangent-cone) approximation. A second relation between these quantities is provided by the Prandtl boundary-layer equations. For both strong and weak interactions over inclined wedges, for example, the governing viscous interaction parameter is $(\text{Mach Number})^3/(\text{Reynolds Number})^{1/2}$.

The straightforward approach to this problem seems to be adequate when the Reynolds Number based on leading-edge thickness, Re_t, is a few hundred, or less. For larger Re_t the experimentally measured induced pressures on flat surfaces suggest that the strong bow shock decays surprisingly slowly at high Mach Numbers and that the expansion waves reflected from this shock and impinging on the surface may overwhelm the purely viscous effect.

For blunt bodies the modified Newtonian approximation in the form $C_p/C_{p_{max}} = \sin^2 \theta_b$ is highly accurate for Mach Numbers above 2.0, even for shapes with rapidly varying (convex) curvatures. Current treatments of heat transfer over such bodies are limited to small temperature differences between gas and body surface. For this case, the agreement between Sibulkin's theoretical result and experiments in the Mach Number range $2 < M < 5$ is good. For large temperature differences an expression quite similar to Sibulkin's is derived, based on gas properties evaluated at the surface temperature. This problem appears to be a fruitful one for the investigation of the influence of high-temperature gas phenomena on hypersonic fluid mechanics.

On the Behavior of Boundary Layers at Supersonic Speeds

by Reginald J. Monaghan

Principal Scientific Officer, Aerodynamics Department, Ministry of Supply, Royal Aircraft Establishment, England

This paper considers the implications of recent advances in knowledge of the behavior of boundary layers in supersonic flow. Only the simplest case is considered—that of the two dimensional boundary layer on a flat plate, with nominal zero longitudinal pressure and temperature gradients.

It is shown that the empirical "intermediate enthalpy" used with success in approximations for skin friction, etc., of laminar boundary layers is closely the same as the mean enthalpy with respect to velocity. Furthermore, the mean enthalpies of laminar and turbulent boundary layers may be the same. A nonrigorous approach is made to the problems of self-induced pressure gradients, and the indications are that their effects on laminar skin friction, etc., may become noticeable at Mach Numbers greater than 5 and that they increase as the surface temperature builds up towards zero heat-transfer conditions. The effects with turbulent boundary layers may not be as severe.

Finally, the results are applied to give an idea of the magnitude of the drag and aerodynamic heating problems up to $M = 10$, and one result is that, if there is any conflict at the higher Mach Numbers between surface conditions required for high radiative emissivity and those that may be thought necessary for preserving a laminar boundary layer, then it may be better to choose the former.

Some Results of the Princeton University Smoke Flow Visualization Program

by David C. Hazen

Assistant Professor, Department of Aeronautical Engineering, Princeton University

A general discussion of the principles of subsonic flow visualization by means of smoke is given. A technique for determining the lift curves of two-dimensional profiles from the photographed streamline patterns is developed. A general description of the Princeton University smoke tunnels within which this work was conducted is presented, along with examples of typical test results. The paper serves as a commentary to a 16-mm. motion picture film that demonstrates the type of work so far conducted.

The experimental results obtained are divided into three groups corresponding to the studies made in each of the three tunnels. The 2 in. by 14 in. tunnel, the smallest of the three, has been used primarily for vortex stability studies. A series of studies of flat plates and circular cylinders generating starting vortices and a Kármán street are shown. The effect of splitters extending up- and downstream upon the vortex stability is explored, as is the influence of shrouds or cowls behind the vortex generator. These tests were extended to examine the effects of various forms of boundary-layer and circulation control. Finally, pictures of a suction stabilized vortex are presented.

The work in the 2-in. by 36-in. two-dimensional tunnel has been of a more applied nature, although some results obtained from high-speed movies of the flow past various patterns of cylindrical obstacles are shown. Use is made of color photography to show the equivalence of a "free-stream" and a "splitter-stabilized" stagnation point on a "lobster-pot" profile such as that studied by the Cambridge University group. Profiles equipped with various forms of boundary-layer and circulation control systems are examined, and high-speed motion picture studies of blowing jet structure and boundary-layer transition are presented. The results obtained by utilizing the high-speed photographic technique to study a profile oscillating in pitch are also given.

The pictures taken in the 12 in. by 16 in. three-dimensional tunnel are perhaps the most revealing of all. Three types of models are shown—rectangular, swept, and delta wings. Various combinations of flat and aileron deflection are examined. The effect of the strong spanwise subboundary layer flow that occurs at low angles of attack is explored. Various special photographic techniques are employed to examine the tip vortex, the three-dimensional flow field of the wake, and the boundary-layer transition pattern. The three-dimensional effects of boundary-layer control are also demonstrated.

The techniques developed in the three-dimensional smoke tunnel are extended to an examination of the wake below a hovering helicopter rotor.

Fatigue of Pressure Cabins

by P. B. Walker

Head of Structures, Royal Aircraft Establishment, England

Pressure cabin fatigue is discussed in the light of the latest knowledge, mainly from the standpoint of fundamental design and full-scale testing. The general stress pattern of a pressure cabin is first discussed, and it is seen that quite elementary principles give essential clues to the designers' problems and are also essential for the planning and interpretation of full-scale fatigue tests.

The loading actions on a pressure cabin are next considered from the fatigue standpoint. It is shown that, while pressure loading is the primary loading, there are other loadings that cannot safely be ignored and some that are not as yet fully understood. Finally, a description is given of the latest equipment developed at RAE for fatigue testing of pressure cabins in water. The construction of the testing tank and gear is described, and information is given concerning the types of failure this method of testing produces.

Some Influences of Equipment Installations and Systems on Aircraft Design

by C. F. Joy

Chief Designer, Handley Page, Ltd., England

While equipment and installations may tend to spoil good airplane design, they are essential to ensure its proper functioning.

The modern trend is toward the "weapons system," whereby air-frame and equipment design, and installation of the latter, proceed side by side.

Chairmen Hall Hibbard *(left)* and George Edwards *(right)* discuss first paper in their session with P. B. Walker *(center)*.

Engine installation has probably the largest effect on air-frame design, particularly on modern multijet aircraft. Podded engines have many advantages, but for a comparable range/load performance buried engines offer better take-off and maneuverability at altitude. Buried engines present problems on intake design, localizing fire damage, and ease of maintenance, but these can be overcome. Supersonic cruising speeds will aggravate these problems.

Aerial systems, etc., on modern bombing aircraft may determine the structural design of the whole fuselage. The large radar scanner, in particular, has a big effect on the layout and general design of front fuselages.

Electrical power generation is undergoing changes because of rapidly increasing requirements and the widespread tendency to adopt a.c. Standardization of radio and radar supplies can effect an appreciable saving in weight and complexity.

"Power boost" controls do little to alleviate existing problems, but "all power" places no limitations on the basic layout and design of control surfaces. The integrated power control system will lead to overall simplification and widen the scope for optimum air-frame design. Reliability, provision of stand-by facilities, and the maintenance of installed stability are fundamental problems in power control design.

Air conditioning and pressurization are essential on high-flying jet aircraft, and the latter imposes serious structural problems. Jet-engine aircraft have adequate sources of high pressure and temperature air. Supersonic speeds will introduce cooling rather than heating problems, which leads to an integration of cooling and auxiliary power generating systems.

Fuel tanks and systems demand early design consideration on long-range multijet aircraft owing to the problems of stowage and c.g. travel limitations. The proportionate use of fuel can be ensured by electronic or mechanical systems. High-altitude flying has led to fuel tank pressurization, which in turn has a considerable effect on structural design, particularly of wings.

Crew escape, when provided by means of a jettisonable cabin, can influence materially the fuselage structural design. Ejection seats affect crew layout and pressure cabin design.

Powered systems on modern aircraft are complicated, and their requirements demand a carefully detailed analysis if an efficient solution is to be found.

"Black boxes" or electrical and electronic components have become large and heavy and repay early consideration of their installation. Some require cooling, and this must be carefully engineered to ensure a minimum penalty in aircraft performance.

Weight and bulk of equipment and installations impose serious penalties on modern aircraft performance. Reductions, particularly on long-range aircraft, result in worth-while saving in all-up weight for a given performance. This effect is still more pronounced on aircraft cruising at supersonic speeds.

It is concluded that the optimum installation of equipment and systems, generally, influences basic aircraft design to a considerable extent.

Power Control Systems for Aircraft

by J. W. Ludwig

Staff Engineer, Controls and Hydraulics, Chance Vought Aircraft, Inc.

As airplanes have developed, the reliability of the control system first increased and then, in later years, decreased. This trend has been brought about by the increase in design requirements. For adequate airplane reliability, this trend must be reversed. Improvements in design simplicity are possible if the controls designer recognizes the entire problem at the outset and is able to approach it as a single problem rather than an agglomeration of separate ones.

Design improvements in control servos should lead to sizable weight and cost reductions. These developments should be adequately supported by statistical reliability test programs. If the confidence level of the designer is to be sufficiently high, these programs will be much more extensive than is presently the practice. The flight-test phase of control systems development is the final step, and an understanding of the pilot's characteristics must exist if this program is to be planned properly so that valid test results will be obtained.

Jet Noise

by F. B. Greatrex

Chief Development Engineer, Installation Division, Rolls-Royce, Ltd., England

Detailed measurements have been made of the noise field around various jet engines, particularly the Avon. The total acoustic power output varies as the 9th power of the jet velocity in good agreement with Lighthill's theory of jet noise. The advantage of the low jet veloci-

ties used in a by-pass type of engine has been confirmed by direct comparison with a Conway engine that was found to be 9 db. quieter at the same thrust.

Of the various noise-reduction devices tested, the "toothed" nozzle has been discarded owing to its adverse effect on engine performance. A series of "corrugated" nozzles having no effect on engine performance has been found to give worth-while noise reductions. The frequency at which the reduction is obtained varies with the width of the corrugations, and the amount of the reduction varies with their depth. Peak reductions of 12 db. have so far been obtained, corresponding to 7 db. reduction in total acoustic power output. A crude picture of the way in which the noise source distribution is related to the spread of the jet may assist practical attacks on the jet-noise problem.

The three main conditions under which jet noise affects the community are examined:

(1) During ground-running; shown to be effectively silenced by a ground muffler.

(2) From aircraft passing overhead during take-off and approach; measured to be 9 db. worse on take-off with standard jet engines than with propeller engines, but can be reduced to the same level with by-pass type of engines and corrugated nozzles.

(3) Inside aircraft (together with the associated structural fatigue); can be controlled by design of the aircraft to avoid known high-intensity parts of the noise field.

Combustion for Aircraft Engines

by W. T. Olson

Chief—Fuels and Combustion Research Division, NACA, Cleveland

The paper discusses the problem of combustion for turbojets, afterburners, and ram-jets. The many aspects of this problem arise from two factors: (1) the extreme range and rapid variations of operating conditions encountered and (2) the many requirements of the combustor, some of which necessitate compromises in the design. The main things the designer must achieve are efficient, high heat-release rates, low pressure drop, suitable outlet temperature profile, and reliability. Reliability includes such items as durability, easy ignition, and rapid response to changes. The literature on the basic processes and phenomena in aircraft-engine combustors is large and growing. This information, coupled with direct engineering experience, has provided design ideas and insights which assist in meeting the advancing needs of the art. Some of this information and experience is discussed.

High combustion efficiency is increasingly hard to get at the high velocities imposed by high mass flow engines; it is also affected adversely by the low pressures at high altitudes. Several basic facts about combustion make it evident that three things are required for high combustion efficiency in a high-speed combustion system: (1) preparation of mixtures that fall within a narrow range of composition near stoichiometric, (2) sufficient time and temperature in order to bring the incoming charge to ignition or flame conditions, and (3) adequate time and space or volume for the turbulently burning mixture to burn completely. In afterburners and ram-jets, basic information for fuel spreading and evaporation assists the problem of matching fuel distribution to airflow to obtain proper mixtures at the flame stabilizers.

Pressure loss can be calculated, as can airflow distribution along can-type combustors.

Data on jet penetration and mixing provide only approximate answers to the problem of obtaining a desired combustor-outlet temperature profile. There is still much artistry connected with this subject.

Combustor wall cooling is more difficult when wall temperatures are increased by increases in both convection and radiation at high pressures and temperatures. Carbon deposits, which increased with fuel rates, reflect strongly the quality of the fuel.

High ignition energies are required, but the energy is influenced strongly by the local environment around the igniter and somewhat by the fuel volatility.

The value of research on isolated problems or processes will be secured only when all the problems are solved together. The inevitable design compromises must be made when the ideas and knowledge furnished by research are integrated into a combustor.

Low Consumption Turbine Engines

by A. A. Lombard

Chief Engineer—Aero Division, Rolls-Royce, Ltd., England

There is no aspect of turbine engines more restricted by "security" than that of fuel consumption; this naturally limits the way in which the subject may be treated. No details of component efficiencies can be stated, and fuel consumption can be referred to only in "relative" terms.

It does, however, encourage one particular aspect to be dealt with rather thoroughly, that of the relative importance of specific weight and specific consumption. It is an aspect that, judged by results, has not received the attention it deserves.

There is clearly a limit to the increase in weight that may be tolerated to achieve a better consumption—e.g., by working at higher pressure ratio. An expression is derived for converting specific weight into terms of specific fuel consumption as an aid to determining the optimum engine for any particular aircraft duty.

Progress in the reduction of fuel consumption has been made largely by the introduction of a new engine type rather than by the progressive development of a given type; this is characteristic of the evolution of any new form of prime mover.

Unless there is a gas-turbine configuration that has been overlooked, which is unlikely in view of the effort expended on the problem, further progress in reducing

fuel consumption will be made by greater attention to detail engineering, to engineering refinement.

Within the limitations mentioned previously, a picture is presented of the relative efficiency of various forms of engine over a range of flight speed, and this is followed by a comparison of the high pressure ratio jet and a by-pass engine—each designed with the same skill, for the same duty, and with the same assumptions. For the high subsonic cruise speed there is a small but definite advantage in the by-pass engine.

The propeller turbine is placed in the short to medium range application for cruising speeds up to 425 m.p.h. The benefit of high flame temperature is discussed, and progress now being made in air-cooled turbine components will result in considerable improvement in performance of the propeller turbine.

Inlet Duct-Engine Flow Compatibility

by Joseph S. Alford

Mechanical Engineer, General Electric Company

The paper discusses the following programs for improving the compatibility of air induction systems and jet engines:

(1) Design of induction systems for good flow distribution.

(2) Flow redistributing devices.

(3) Design of jet engines to tolerate moderate distortion.

(4) Engine controls.

(5) Matching of inlet duct flow distortion to engine requirements.

In order to obtain the best performance from jet engines designed for supersonic flight speeds, the compressor airflow should be as high as possible at intermediate corrected engine speeds. For example, because of the ram temperature rise of flight Mach Number 2.0, the engine operating at full mechanical speed will have a corrected speed of only 85 per cent. At this intermediate corrected engine speed, the front stages of the compressor operate at high aerodynamic loadings. Areas of low axial air velocity at the compressor inlet will result in increased angles of incidence of the air on the blading and will cause stall to occur earlier in these local regions. Since a high airflow capacity is dependent on developing a substantial pressure rise through these early stages, those types of inlet air distortion patterns that reduce the pressure rise through these front stages will directly reduce the airflow capacity and hence the thrust of the engine.

Factual information is presented on the characteristics of a modern jet engine as regards toleration to various types of inlet flow distortion. Investigations include the effects of circumferential distortions having one and two loss areas per revolution and of radial distortions having loss areas at hub and at tip. For the particular jet engine and inlet flow patterns investigated, radial distortion characterized by low axial inlet velocity at blade tip was found to have the greatest effect on performance at corrected engine speed corresponding to flight at Mach 2.0.

Power Plants for Supersonic Flight

by E. S. Moult

Chief Engineer, The de Havilland Engine Co., Ltd., England

The paper reviews possible types of power plant suitable for propelling manned aircraft at speeds equivalent to Mach 2 or Mach 3 in the stratosphere. Consideration is given to the liquid-fuel rocket, the ram-jet, the turbojet, and the turbojet with afterburner. These units are compared when adjusted in size to give the same thrust at a speed of Mach 2 at 36,000 ft. altitude.

Assuming representative values for drag coefficient, the level-flight performance envelopes are compared.

Romanoff's restaurant is the scene of a luncheon given by Robert E. Gross and Lockheed Aircraft in honor of the British delegates.

The Fifth International Conference and Honors Dinner, held at the Hollywood Palladium, is attended by approximately 1,400 people. Presentation of the Thurman H. Bane Award to Gottfried Guderley *(left)* and the Octave Chanute Award to Major Gen. Albert Boyd (through Lt. Gen. Donalt Putt, *right*) is made by IAS President Robert Gross *(center)*.

The importance is stressed of a margin of thrust over drag to permit climb, to give rapid acceleration from one speed to another, and to provide good maneuverability. In this connection, there are advantages from the use of mixed power plants.

After a brief consideration of relative weights, sizes, and fuel consumptions, the paper deals at some length with the effects of high-speed flight on the design and performance of a turbojet engine. Great importance is attached to the need for an efficient intake system, which at high speeds contributes more to the compression process than the engine itself.

The effects of ram not only determine the working temperatures and pressures through the unit but influence the choice of the basic design parameters. At high speeds of flight there are special attractions in high-temperature operation and in afterburning. These considerations affect the design of the compressor, the combustion chamber, the turbine, and the exhaust system.

Cooling problems will be severe not only in the engine itself but in the associated services. Air bled from the compressor may serve many useful purposes. The author concludes that the engine for supersonic flight is essentially a compact and powerful unit that, by its design requirements, will be robust, simple, and of light weight for the thrust developed.

Thursday, June 23

▸ **Hollywood Tour and Luncheon**—A bus tour of the Hollywood area, including a trip through one of Universal's movie studios, was arranged for the British delegates and their wives. As guests of IAS President Robert M. Gross and the Lockheed Aircraft Company, the group was treated to a noon luncheon at Romanoff's famous restaurant.

▸ **Palmdale Field Trip**—While the British were seeing something of Hollywood, approximately 200 security-cleared Americans spent the day inspecting the Palmdale facilities of Lockheed, North American, and Northrop aircraft companies. Leaving by busses, after a 6:30 a.m. breakfast at the IAS building, the group spent the entire day at this desert Air Force base. Luncheon was served at the cafeteria of the North American plant.

▸ **Conference Dinner**—A social hour, with dancing to the music of Harry James' and Oren Tucker's orchestras preceded the Conference Dinner at the Hollywood Palladium on Thursday evening. Some 1,400 people attended this affair, which featured a maximum of entertainment and a minimum of formality.

Introduction of guests at the head table by IAS President Robert Gross, brief remarks by the presidents of both societies, and presentation of the Bane and Chanute Awards and of a special plaque to Past-

IAS Building at San Diego, Calif.

Mr. and Mrs. N. E. Rowe, T. Claude Ryan, Mrs. J. T. McNarney, Robert E. Gross, Mrs. Ryan, and Gen. McNarney *(from left to right)* at San Diego.

Major Reuben H. Fleet, a past president of Convair and of the IAS, gives a few words of welcome to the RAeS visitors at the dinner held in their honor at the Hotel del Coronado.

President Reuben H. Fleet constituted the formal part of the program. (Details of these Awards and Honors were reported in the August REVIEW). The balance of the evening was spent in dancing.

Friday, June 24

▸ **San Diego Party**—As guests of the Institute's San Diego Section and the local aircraft industries, British delegates and their wives were treated to a 2-day visit to California's southernmost coastal city. Transported in three modern Greyhound busses, the group left Hollywood on Friday morning and arrived in time for a buffet luncheon, served in the auditorium of the Institute's San Diego building.

The 140-mile drive down the Coastal Highway was broken in midmorning for a "coffee-break" at the little town of San Clemente. Here, many of the British visitors were introduced for the first time to a variety of American "doughnuts."

A special program for the ladies, including a luncheon at Cafe del Rey Moro, Balboa Park, a tour of San Diego, and tea at the home of Mr. and Mrs. Reuben Fleet, was carried out by wives of the local IAS officers. Meanwhile, the visiting delegates toured the facilities and plants of Convair, Ryan Aeronautical Co., Solar Aircraft Co., and Rohr Aircraft Co. (the latter at Chula Vista), according to their elected choices.

All tours terminated about 5:30 at the Hotel del Coronado where the guests were housed for the night. A 7:30 reception in the Circus Room of this colorful

At Convair's plant, the delegates visit the production line of the F-102 and also have an opportunity to inspect closely the Navy's "Sea Dart" *(top left)* and the experimental VTO *(top right)*.

A briefing outside the plant *(center, left)* precedes an inspection of the USAF Q-2A target drone airplane *(center, right)* and the many components production facilities of Ryan Aeronautical Co.

Solar Aircraft Company demonstrates some of their small gas-turbine engines and other products *(bottom left)* before Solar's president, E. T. Price, allows N. E. Rowe, R. H. Weir, and the other British visitors to test the cake baked in their honor *(bottom right)*.

old resort hotel, followed by dinner and dancing at 8:30 in the Main Ballroom, brought the day's program to a happy and successful conclusion. (For many, this was in the wee hours of the morning.)

Saturday, June 25

The trip back to Los Angeles was started in mid-morning, after a breakfast of personal choice at the del Coronado. This time, the busses followed the inland route through the scenic back country and mountains.

▸ **Old Mission Inn**—Luncheon at the Old Mission Inn, in Riverside, was a highlight of the return trip. Several hours were allowed for the visitors to wander through the catacombs, buildings, and grounds of this restored old mission before returning to Los Angeles.

▸ **Barbecue**—The evening program consisted of a typical Western-style barbecue—with meats cooked for 20 hours in earth-dug pits and all the trimmings—at Verdugo Park, in Glendale. For those who didn't eat too much and could take it, a spirited softball game between friendly rivals got under way in the twilight hours.

The Verdugo Dons, a male quartet, provided musical entertainment in the early evening. Their program was overshadowed, however, by the later impromptu show put on by some of the British visitors, with RAeS president N. E. Rowe leading the singing to the accompaniment of W. F. Hilton's miniature ukulele.

It must be admitted that our British friends proved their sportsmanship and stole the show at what was purported to be a typically American picnic.

Sunday, June 26

This was the only "open day" during the conference, and many of the visitors used it to take advantage of the Hollywood-Roosevelt's inviting swimming pool. Others visited friends, went sightseeing, or found other forms of entertainment.

A cocktail party, given by Mr. and Mrs. George Starbird at their home, was enjoyed by many in the late afternoon.

Monday, June 27

▸ **Plant Tours**—The second week of the conference was devoted to visits to some of the outstanding aviation plants and facilities in the Los Angeles and Central California areas. Because of the diversified interests of the British visitors, an optional choice of tours was given wherever practical.

Douglas Aircraft Company, Inc.—Tour No. 1 included a visit to the "home" plant of Douglas, at Santa Monica, in the morning, and an inspection of the company's El Segundo facilities in the afternoon. At the former, the

The outdoor barbecue *(top photos)* is highlighted by some impromptu singing led by N. E. Rowe and W. F. Hilton *(background).*

Donald Douglas, Jr. *(3rd photo)* explains some of the features of the DC-8 jet transport during a visit to the mock-up section *(bottom photo)* of the Douglas Santa Monica plant.

guests were shown the production lines of the "DC" series of transport aircraft and the "Nike" (ground-to-air) guided missile. A visit to the plant's electronic computing department and some of its research and testing sections was also included.

After a large luncheon at the Del Mar Club, where Donald Douglas, Jr., acted as host, the group was transported to El Segundo. This division, which is devoted to the design and production of Naval carrier-based aircraft, gave the visitors a chance to see the latest F4D, A4D, and A3D aircraft, under the personal guidance of the division's chief engineer, Ed Heinemann.

California Institute of Technology—Those who elected to take Tour No. 2 on this same day spent the morning at the Guggenheim Aeronautical Laboratory, the Jet Propulsion Laboratory, and the industry-owned Southern California Cooperative Wind Tunnel—operated by the university. C.I.T. is one of the country's leading schools offering an aeronautical engineering curriculum.

Aerojet-General Corporation—A luncheon at Eaton's Santa Anita restaurant preceded the afternoon visit to this subsidiary corporation of The General Tire & Rubber Company. Here, the visitors saw the solid- and liquid-propellant thrust-augmentation units and power plants designed and manufactured by this company for aircraft and missile use. Dan Kimball, President of Aerojet, was the host.

Tuesday, June 28

North American Aviation, Inc.—Tours No. 3 and No. 4 were combined for the morning, with both groups visiting the home plant of North American, at Inglewood. The freedom of movement accorded here gave the delegates ample opportunity to study the modern tools and machinery used to produce the USAF's series of F-86 and F-100 "Sabre jets."

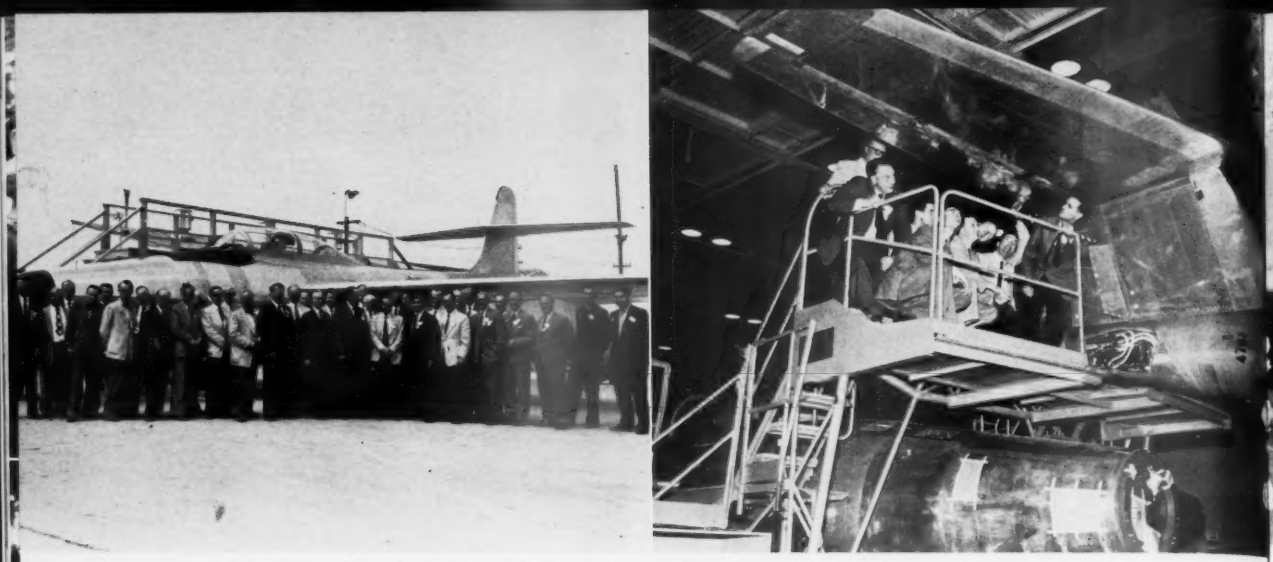
Northrop Aircraft, Inc.—The Tour No. 3 group became the guests of Northrop at noon for a luncheon at the Cockatoo Restaurant. This was followed by an inspection of the company's Hawthorn facilities, currently in production on the F-89 "Scorpion" series of all-weather interceptors and the "Snark" pilotless bomber for the USAF.

Marquardt Aircraft Company—Group No. 4 was transported to Van Nuys, where Roy Marquardt and the officers of this company played hosts at a luncheon in the plant cafeteria. The rest of the afternoon was spent seeing something of Marquardt's development and production of ram-jet engines, jet-engine afterburners, and associated controls.

▸ **AIA Theater Dinner Party**—As special guests of the Aircraft Industries Association, the delegates were invited by Capt. Lee Webb to a dinner party at Holly-

(Top) A pause for a picture on the flight line precedes the group's visit to the production facilities of Douglas' El Segundo plant *(2nd photo)*.

At North American, the visitors have ample opportunity to study the F-100 "Sabre jet" *(3rd photo)*, as well as the modern equipment and machines used to produce it *(bottom photo)*.



The group on Tour No. 3 visits the Northrop Aircraft plant and gives the F-89 "Scorpion" a thorough going-over.

wood's Moulin Rouge. Cocktails, dinner, a bit of dancing, and a 2-hour show was the order of an enjoyable evening.

Wednesday, June 29

Lockheed Aircraft Corporation—Burbank, and the home plant of Lockheed, was the objective of the Tour No. 5 group during the morning of this day. With Air Force fighters, Navy "Neptune" patrol bombers, and a series of "Super-Constellation" transports in production, this facility gave the British a fairly broad picture of America's aircraft manufacturing methods.

"Bob" Gross and Hall Hibbard played hosts to the group at a luncheon in the Air Terminal "Sky Room."

Chevrolet Assembly Plant—An afternoon visit to this major West Coast Chevrolet plant gave the delegates an opportunity to see a typical example of assembly-line mass production techniques used by the automotive industry.

Zenith Plastics Company—The Aircraft Division of this company is a major producer of radomes and large structural components for the aircraft industry. Methods currently in use for the fabrication of such plastic parts were demonstrated to those delegates who selected Tour No. 6 for this date.

Luncheon was served to the group at The Palms Restaurant.

Harvey Aluminum Division—Tour No. 6 moved on to this division of the Harvey Machine Co., Inc., in the afternoon. Here, the methods for producing aluminum extrusions, sheet, bar, etc.—from ingots to finished products—were demonstrated.

▸ **Farewell Buffet**—Since this was the last day scheduled for the delegates in the Los Angeles area, a reception and buffet dinner was held at the Institute's building to give the local officers and delegates an opportunity to bid their farewells. Some 250 people, including most of the local IAS people who had anything to do with arranging and handling the conference, were present.

Thursday, June 30

▸ **Edwards AFB Trip**—After a 6:30 a.m. breakfast at the Hollywood-Roosevelt Hotel, departure was made

Roy Marquardt bids good-by to S. Scott-Hall and the Tour No. 4 visitors, following an inspection of the plant and an after-lunch briefing.

The RC-121D Early Warning airplane *(left)* and the "Constellation" final assembly line *(right)* evoke considerable interest at Lockheed Aircraft.

by busses for the Burbank airport. Here, a "Super G Constellation" and a Martin 202A, chartered from T.W.A. and S.P.A., respectively, waited to transport approximately 90 visitors to Edwards AFB and Moffett Field.

Colonel Marion J. Akers and staff officers, pinch-hitting for Brig. Gen. J. Stanley Holtoner, who had been called away on emergency duty, met the delegates upon arrival at the base. Preceding a briefing and some movies at the base theater, a leisurely inspection of all aircraft on the flight line was scheduled.

Luncheon at the Officers Club was followed by a trip to the high-speed test tract. Here, the group witnessed a test run of the sled at a speed of Mach 1.6 and experienced the thrill of close proximity to the resulting supersonic shock waves.

A visit to the new Flight Test Laboratory of NACA and an inspection of current experimental airplanes completed the day's tour at Edwards.

Rickey's Inn Dinner—Arriving at Moffett Field, the visitors were met by Ed Quarterman, Chairman of the IAS San Francisco Section, and Hugh Dryden and Smith DeFrance of NACA. Transportation to Rickey's Inn at Palo Alto was handled by Navy busses.

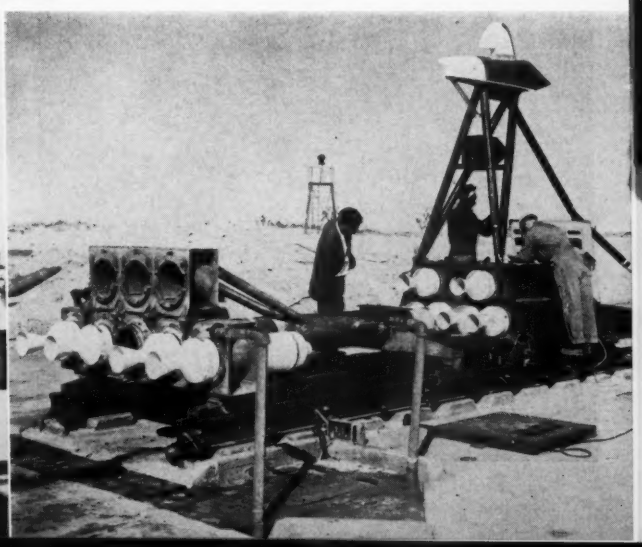
A reception and dinner, sponsored by the San Francisco Section, was held at the Inn, where the delegates were housed for the night as guests of the Institute.

Friday, July 1

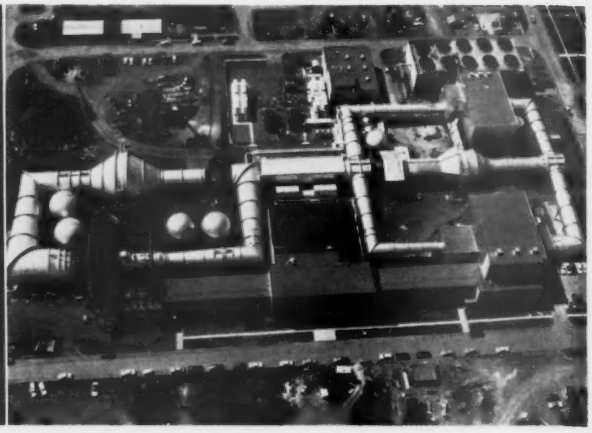
▸ **Ames Aeronautical Laboratory**—This day was devoted to an all-day tour of NACA's Ames Aeronautical Laboratory. With the efficiency and dispatch which mark all NACA "open house" inspections, the Ames scientists gave the British visitors the same demonstrations and talks given at the various installations to American visitors during the Triennial Inspection earlier in the week. A special luncheon was served in the cafeteria of the Laboratory, with Hugh L. Dryden, NACA Director, and Smith DeFrance, Director of Ames Laboratory, acting as hosts.

▸ **Final Reception**—The conference came to an official close with the reception at the Sir Francis Drake Hotel in San Francisco on the evening of July 1. This was arranged by the local IAS Section and was attended by a majority of the Section officers and their wives.

Arrival at Edwards Air Force Base *(left)* and a view of the high-speed rocket sled *(right)* preparatory to a test run.



Hugh L. Dryden, N. E. Rowe, and Smith DeFrance at Ames Aeronautical Laboratory, Moffett Field, Calif.



Aerial view of the nearly completed high-speed wind tunnel being built at Ames as a part of the Unitary Plan.

Ladies' Program

Although the foregoing diary has been chiefly concerned with the official delegates and conference program, this report would be incomplete without special mention of the ladies' affairs and parties. Some 25 British wives accompanied their husbands on the trip, and every thought was given to their well-being and pleasure during their visit to California.

A daily program, which was designed to fill their time while their husbands attended the conference, was arranged and carried out by the ladies of the IAS officers and committeemen in Los Angeles. Highlights of this program included:

- Bus tour of Hollywood and Beverly Hills.
- Shopping tour of Bullock's, Robinson's, I. Magnin's, etc.
- Luncheon at Farmer's Market.
- Theater party, *The Pajama Game*.
- Visit to San Gabriel Mission.
- Lunch and Fashion Show at Bullock's store in Pasadena.
- Huntington Library and Art Gallery, at San Marino.
- Trip to Knotts Berry Farm.
- CBS-TV studio tour, and guests of Art Linkletter on *House Party* program.
- Luncheon at the Brown Derby.
- Visit to Hollywood Bowl and Greek Theater.
- Trip to Padua Hills and the Mexican Theater Players.
- Individual teas and cocktail parties.

IAS President Robert E. Gross, Mrs. Rowe, and RAeS President N. E. Rowe.

On June 30, as the delegates were being whisked off to Edwards AFB, the ladies boarded their own flights at International Airport bound for San Francisco. They were accompanied on this jaunt by Mrs. E. W. Robischon, wife of the IAS Western Region Manager, who had served as principal hostess throughout the entire conference.

Upon arrival, they were met by the officers and wives of the IAS San Francisco Section and taken to the Sir Francis Drake Hotel. An afternoon tour of the city, tea at the Cliff House, and dinner at Fisherman's Wharf was topped-off by a moonlight boatride on San Francisco Bay in the evening.

Trips to Muir Woods and Chinatown were scheduled for the final day, following which the ladies were returned to their hotels in time to greet their husbands for the farewell reception of the conference.

Since the ladies were also included in all of the official social functions connected with the conference, they had a fairly busy and interesting time.

Conclusions and Acknowledgments

In looking back over this Fifth International Aeronautical Conference, it would appear that it could be judged a complete success. Like its four predecessors, it created many new friendships and further strengthened the old ones. It also fostered a better understanding of mutual interests and problems—both technical and personal—on both sides of the Atlantic.

Many people—British and American alike—were involved in making this conference click. To all of them—from the members of the RAeS staff to the IAS Corporate Member companies—goes a vote of thanks.

The ladies have their own parties and fun, as indicated by these pictures taken on one special occasion—and identified in the caption below.

Particular credit is due the Institute's West Coast Section's officers, program chairmen, committeemen, and their wives.

Los Angeles Section Officers

Chairman ..... W. T. Dickinson
Vice-Chairman ..... G. R. Mellinger
Secretary ..... J. W. Wechsler
Treasurer ..... E. W. Hokanson

Los Angeles Conference Program Committee

W. H. Arata, Jr., *Chairman*
A. J. Carah
F. A. Cleveland
R. Davis
T. F. Francis
H. M. Fussell
John Hoch
Walter Hurty
John Kerr
Brooks Morris

San Diego Section Officers

Chairman ..... James G. Wenzel
Vice-Chairman ..... Earl R. Hinz
Corresponding Secretary ..... James M. Adamson
Recording Secretary ..... Donald P. Germeraad
Treasurer ..... Harvey C. Matteson

San Diego RAeS-IAS Arrangements Committee

J. G. Wenzel, *Chairman*
E. T. Austin
P. E. Culbertson
R. A. Fuhrman
W. C. Heath
W. T. Immenschuh
P. M. Klauber
F. E. McCreery
J. T. Porterfield
E. G. Stout

San Francisco Section Officers and Program Committee

Chairman ..... Comdr. E. A. Quarterman
Vice-Chairman ..... L. G. Kelso
Secretary ..... George Cooper
Treasurer ..... F. E. Titus

(Left to right and from top to bottom of the page) **Lady Roy H. Fedden, Mrs. N. E. Rowe, Mrs. Hall Hibbard; Miss Florence Barwood; Mrs. O. N. Lawrence, Mrs. Christopher Dykes, Mrs. A. M. Ballantyne; Mrs. Byron Masterson, Mrs. Charles Colvin, Mrs. T. P. Wright, Mrs. Warren Dickinson; Mrs. E. B. Moss, Mrs. R. Soucek, (Mrs. Masterson); Mrs. Robert E. Gross, (Mrs. Soucek), and Mrs. A. A. Lombard.**

Royal Aeronautical Society Delegates to the Fifth International Conference

Allwright, E. S., Deputy Assistant Chief Designer, Vickers-Armstrongs, Ltd.
Ballantyne, A. M., Secretary, RAeS
Banks, Air Commodore F. R., Director, The Bristol Aeroplane Co., Ltd.
Barrett, A. J., Technical Assistant (Structures), RAeS
Bloch, Lt. Comdr. R. M., Direction Centrale des Constructions et Armes Navales (Bureau Aeronautique), Paris, France
Bloss, H. G., Chief of Aircraft Section, NATO
Boswell, A. C., Assistant Designer, Power Plants, The English Electric Co., Ltd.
Brooks, P. W., Technical Assistant to Chief Executive, B.E.A.
Browning, W., Director and General Manager, Saunders-Roe, Ltd.
Campbell Orde, A. C., Operations Development Director, BOAC
Clark, B. F., Project Designer, Boulton Paul Aircraft, Ltd.
Clark, K. W., Assistant Director, Directorate of Civil Aircraft, Research & Development, MOS
Constant, Hayne, Director, National Gas Turbine Establishment
Cowdray, C. L., Manager, D. Napier & Son, Ltd.,
Crabtree, Hedley S., Consultant Engineer, Hedley S. Crabtree & Co., Ltd.
Crocombe, F. F., Chief Engineer, Boulton Paul Aircraft, Ltd.
Crowe, F. D., Assistant Chief Designer, Aircraft Production, The English Electric Co., Ltd.
Cuss, J. F., Chief Stressman, Gloster Aircraft Co., Inc.
Dickinson, R. P., A. and A. E. E. Boscombe Down
Duddy, R. R., Aero Flight Section, RAE
Dunsby, J. A., Technical Assistant (Aerodynamics), RAeS
Dykes, J. C., Aeronautical Consultant
Edwards, G. R., Managing Director, Vickers-Armstrongs, Ltd.
Ellis, J. C., Squadron Leader, Royal Air Force, in U.S.A.
Fedden, Sir Roy, Past-President, RAeS, Aeronautical Consultant
Fowler, R. G., Chief Aerodynamicist, Folland Aircraft Ltd.
Freestone, Air Commodore L. R. S., British Joint Services Mission, in U.S.A.
Gates, S. B., Chief Scientific Officer, RAE
Giddings, H., Chief Technician, The Bristol Aeroplane Co., Ltd.
Greatrex, F. B., Chief Development Engineer, Installation Division, Rolls-Royce, Ltd.
Greinacher, R., Section Chief (Aviation) Service, Technique Militaire du Départment Militair, Federal Government, Swiss
Gunston, W. T., Technical Editor, *Flight* Magazine
Hall, Sir Arnold, Director, RAE
Hall, G. W., The Fairey Aviation Co., Ltd.
Hampton, W. E., Overseas Aviation Representative, D. Napier & Son, Ltd.
Hatton, C. D., Assistant Chief Engineer, Short Brothers & Harland Ltd.
Heath, W. G., Chief Stressman, A. V. Roe & Co., Ltd.
Hemp, W. S., Head of Department of Aircraft Design, College of Aeronautics, Cranfield
Hemsley, C. G. H., Assistant Chief Designer, Vickers-Armstrongs, Ltd.
Hilton, W. F., Chief Aerodynamicist, Sir W. G. Armstrong Whitworth Aircraft, Ltd.
Holloway, C. F., Technical Advisor, B. P. Aviation Service, British Petroleum, Ltd.
Hollyhock, W. S., Chief Production Draughtsman, Hawker Aircraft, Ltd.
Howarth, R. M., Assistant Chief Designer—Helicopters, The Bristol Aeroplane Co., Ltd.
Hughes, S. R., Chief Aerodynamicist, Vickers-Armstrongs Supermarine Works
James, D., Chief Stressman, Vickers-Armstrongs, Ltd.
James, T. T., Editor, *The Aeroplane*
Jones, Capt. C. W., RN Deputy Director of Aircraft, Maintenance & Repair (Admiralty)
Jones, E. T., Principal Director Scientific Research (Air), MOS
Jones, W. P., Aerodynamics Division, National Physical Laboratory
Joy, C. F., Chief Designer, Handley Page, Ltd.
Keen, E. D., Chief Designer, Sir W. G. Armstrong Whitworth Aircraft, Ltd.
Keith-Davies, E., Chairman, Keith & Boyle; Director, Cambrian Air Services, Ltd.
King, J. C., Experimental & Administrative Engineer, The English Electric Co., Ltd. (Aircraft Division), Warton Aerodrome
Kuchemann, D., Principal Scientific Officer, RAE
Lachmann, G. V., Director of Research, Handley Page, Ltd.
Laight, B. P., Chief Designer, Blackburn & General Aircraft, Ltd.
Lance, G. N., Research & Lecturing at California Institute of Technology
Lawrence, O. N., Technical Director, Joseph Lucas (G.T.E.), Ltd.
Lickley, R. L., Chief Engineer, The Fairey Aviation Co., Ltd.
Lombard, A. A., Chief Engineer, Aero Division, Rolls-Royce, Ltd.
Loveless, E., Chief Stressman, The English Electric Co., Ltd.
Masefield, P. G., Chief Executive, B.E.A.
McClure, Wing-Comdr. C. G. B., College of Aeronautics, Cranfield
Monaghan, R. J., Principal Scientific Officer, Aerodynamics, RAE
Moore, C., Associate Director, AGARD
Morgan, M. G., Deputy Director, RAE
Morgan, R. C., Chief Project & Development Engineer, B.E.A.
Moss, E. B., Technical Director, Smiths Aircraft Instruments, Ltd.
Moult, E. S., Chief Engineer, The de Havilland Engine Co. Ltd.
Neal, Mrs. Molly, Assistant Editor, *Engineering*
Nicholl, E. J., Director & Chief Engineer, Dowty Equipment of Canada Ltd.
Nicholson, L. F., Head of Aerodynamics Department, RAE
Palmer, J. R., Department of Aircraft Propulsion, College of Aeronautics, Cranfield
Pearlman, H. S., Aeronautical Engineer, El Al Israel Airlines, Ltd.
Peduzzi, A. M., in U.S.A.
Penn, A. J., Chief Engineer, Aero Gas Turbine Division, D. Napier & Son, Ltd.
Pike, Miss E. C., Technical Assistant, RAeS
Pringle, R., The English Electric Co., Ltd.
Prower, C. W., Assistant Chief Designer, Blackburn & General Aircraft, Ltd.
Quinn, N. R., Chief Aerodynamicist, Engine Division, The Bristol Aeroplane Co., Ltd.
Rabek, J. W., in U.S.A.
Rainbow, H. S., Chief Project Designer, Aero Department, Armstrong, Siddeley Motors, Ltd.
Remfry, J., Assistant Director, Engine Research & Development, MOS
Richardson, C. A., Aeronautical Manager, The Sperry Gyroscope Co., Ltd.
Ripley, E. L., Principal Scientific Officer, Head of Accident Section, RAE
Rochefort, H. E. J., Chief of Research & Development, Hawker Aircraft, Ltd.
Roe, F. E., Principal Engineer, Wind Tunnels, The English Electric Co., Ltd.
Rosenthal, L. W., Coordinating Engineer, Saunders-Roe, Ltd.
Rowe, N. E., Technical Director, Blackburn & General Aircraft, Ltd.
Russell, C/Capt. H. M., RAF Officer in U.S.A.
Sargent, R. F., Assistant Engineer-in-Charge, Ramjet Aerodynamics and Performance, Engine Division, The Bristol Aeroplane Co., Ltd.

(*Continued on page 90*)

A description of various systems for maintaining aircraft balance by means of fuel management and a design that allows for the use of the same tank units in both gaging and balancing.

Automatic Control of Aircraft Center of Gravity

Maxwell J. Lawrence*
Avien, Inc.

Introduction

Since a considerable portion of the gross weight of an aircraft consists of fuel, it becomes necessary to route the fuel to the engines in such a manner that the aircraft remains approximately in balance. If the center of gravity keeps shifting because of fuel consumption, the tail trim tabs must accordingly be adjusted to maintain a constant aircraft pitch angle. Although this can be done automatically, the range of trim tab adjustment is usually too small to accommodate gross fuel unbalances. Furthermore, it is usually desirable to maintain the trim tabs at the center of the range to minimize drag.

For these reasons, a fuel withdrawal program is frequently used whereby the engines are switched manually from tank to tank in order to maintain aircraft balance. This program requires that the pilot have a means of gaging the amount of fuel withdrawn from each tank.

Until recently, most of the fuel was located in the wing tanks the centroids of which were relatively close to the aircraft center of gravity. As a result, the total moment about the center of gravity due to fuel was a small percentage of the total moment for the aircraft, and consequently gross fuel unbalances were not common.

The modern trend, however, is toward thinner wings which means that more fuel must be located in the fuselage and at greater distances from the aircraft center of gravity. This has brought about the necessity for some means of control of aircraft balance by programing fuel either manually or automatically. This paper describes several systems for automatic control of an aircraft center of gravity by means of fuel management.

Theory of Operation

If two conducting plates are immersed in a tank of fuel, they form a capacitor, with the fuel as a dielectric. Since there is a close relationship between the density and dielectric constant of aviation fuel, the weight of fuel in the tank can be determined by measuring the capacitance. By shaping the electrodes to conform to the capacitance vs. level curve of the tank, a linear relationship between capacitance and weight of fuel will result. The assembly containing the shaped electrodes is known as a "profiled tank unit."

Consider two tanks containing fuel of weights W_1 and W_2 and located from the c.g. of an aircraft by distances L_1 and L_2, respectively.

If a profiled tank unit is inserted in each tank, then $W_1 = K_1C_1$ and $W_2 = K_2C_2$ where the K's are constants of proportionality and the C's are the capacitances of the respective tank units.

For balance about the c.g.:

$$W_1L_1 = W_2L_2 \tag{1}$$

$$\text{or} \quad W_1/W_2 = L_2/L_1 = K_1C_1/K_2C_2 \tag{2}$$

If the two capacitors are now connected in the form of an a.c. bridge as shown in Fig. 1, and the bridge balanced electrically:

$$C_1/C_2 = V_2/V_1 = K_2\,W_1/K_1\,W_2 = \text{constant} \tag{3}$$

This means that, if the ratio of C_1 and C_2 is held constant and equal to $K_2\,W_1/K_1\,W_2$, the fuel system will always be in equilibrium.

Assume, now, that the relay of Fig. 1 controls a pump (valve or other electromechanical device) which transfers fuel from tank 1 to tank 2 and that tank 2 feeds the engine. Starting with the balanced condition, the bridge output is zero and the relay is unenergized. As the engine consumes fuel, the level in tank 2 decreases, resulting in a corresponding decrease in C_2 with the result that a higher and higher bridge output voltage appears at the input to the amplifier. When this voltage exceeds a predetermined limit, the relay energizes, causing the pump to transfer fuel from tank 1 to tank 2. While the pump is operating, C_1 is decreasing, C_2 is

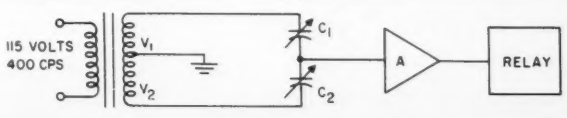


Fig. 1. Basic c.g. control circuit.

* Formerly with Avien, Inc., as Assistant Chief Electrical Engineer.

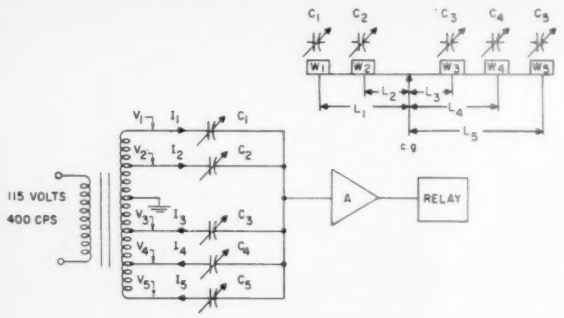


FIG. 2. Multitank balancing circuit.

increasing, and the bridge output voltage is approaching zero. When it becomes sufficiently small, the relay drops out, disconnecting the pump, for the system has now rebalanced.

The higher the amplifier gain, the more frequent the pump operation and the shorter the pump life. On the other hand, the lower the amplifier gain, the greater the unbalance before the pump operates. This means that a fixed gain amplifier having a gain consistent with pump life and fuel unbalance must be used.

The system just described is known as a capacitance-fed system, since the sensing elements are capacitors. Another system that is in use is known as a voltage-fed system. In this system, if the weight of fuel in each tank appears on an indicator in which dial rotation is proportional to weight of fuel, then a proportioning potentiometer in each indicator can be connected to produce a voltage proportional to fuel weight. When these voltages are connected to an adding network that feeds an amplifier and relay, the operation becomes similar to that of Fig. 1.

Although a relay is shown in Fig. 1, any voltage-sensitive detector may be used in its place. When a zero-center meter or positional servo is used, the deflection will indicate the degree as well as the direction of unbalance. In the case of the positional servo, the addition of limit switches to the indicator will enable it to function both as an indicator and as a relay.

Multiple Tank System

The balancing system may be designed for use with any number of tanks by inserting a profiled tank unit in each tank and connecting the tank units as shown in Fig. 2. Here, five tanks have been chosen with two on one side of the c.g. and the other three on the other side.

Then for mechanical equilibrium

$$W_1L_1 + W_2L_2 = W_3L_3 + W_4L_4 + W_5L_5 \qquad (4)$$

Since $W_n = KC_nC_n$, where K_n is the individual tank unit scale factor, C_n is the individual tank unit capacitance, and W_n is the weight of fuel in each tank:

$$(K_1L_1)C_1 + (K_2L_2)C_2 = (K_3L_3)C_3 + (K_4L_4)C_4 + (K_5L_5)C_5 \qquad (5)$$

For bridge balance

$$I_1 + I_2 = I_3 + I_4 + I_5 \qquad (6)$$

Dividing through by W

$$V_1C_1 + V_2C_2 = V_3C_3 + V_4C_4 + V_5C_5 \qquad (7)$$

Thus, if $V_1 = K_1L_1$, $V_2 = K_2L_2$, $V_3 = K_3L_3$, $V_4 = K_4L_4$, and $V_5 = K_5L_5$, the conditions for both electrical and mechanical equilibrium will be satisfied. Since the K's and L's are constants, the transformer voltages will be fixed, and the system will respond to fuel unbalance regardless of the distribution of fuel in the tanks.

The operation of the system described thus far was based upon level flight. For applications where it is expected that the aircraft attitude will deviate considerably from the level flight condition, a number of tank units must be inserted in each tank and connected in parallel as in standard capacitance fuel quantity gaging systems. The capacitance of each C_n previously described will then be the sum of the individual tank unit capacitances. Furthermore, the profiling of each tank unit will be such that the capacitance C_n will be proportional to the weight of fuel in tank n over the range of attitudes chosen, with the same constant of proportionality regardless of attitude.

Accuracy

The overall system accuracy is affected by the following sources of error: (1) variations in K; (2) profiling; and (3) calibration, system sensitivity, component tolerances, environmental conditions.

(1) In practice, the dielectric constant of fuel may vary from sample to sample by as much as ± 10 per cent from the nominal. As it does, however, the density also changes in accordance with the following nominal formula:

$$(K - 1)/D = 0.12913\ [1 + 0.2850(K - 1)] \qquad (8)$$

where K is the dielectric constant and D is the density in pounds per gallon.

In capacitance fuel quantity gaging systems, automatic compensation for variation in K is accomplished by the use of a small auxiliary tank unit that is always submerged. In balancing systems, unless the tare is extremely large, this is not necessary since the same percentage change in probe capacitances in the bridges of Figs. 1 or 2 will not affect bridge balance. Even in systems where there is appreciable tare, the error is quite small, since the tare itself is a small fraction of the total poundage. For instance, in a system in which the tare constitutes 10 per cent of the total poundage on one side of the fulcrum, a 10 per cent error in dielectric constant will give an error of approximately 1/2 per cent of the total fuel poundage.

The tare may be represented in Eq. (7) by a constant and in Fig. 2 by a fixed capacitor connected on the corresponding side of the bridge circuit as though it were another tank unit. The error due to a change in di-

electric constant arises from the fact that all the tank unit capacitances change proportionally with K, while the fixed capacitance does not. If it is desired, therefore, to make the system completely immune to changes in dielectric constant, it is necessary to make the fixed capacitor a small tank unit that is always submerged in the fuel. Then a change in dielectric constant will produce a proportional change in all the terms of Eq. (7), including the "fixed" term, and thus leave the equation unaffected.

(2) Profiling may be accomplished by varying the spacing between the capacitor plates or by varying the plate area in accordance with the contour of the tank. In practice, the maximum error due to profiling is usually in the order of 1/2 per cent.

(3) Calibration is accomplished by the use of standard precision capacitors that have accuracies of 0.2 per cent or 0.2 mmf., whichever is the greater. A good system sensitivity is in the order of 0.2 per cent. The error due to most component tolerances is eliminated during calibration. About the only component tolerance error that remains is that of a linear rebalance potentiometer in positional servosystems which potentiometer need not have a linearity better than about 1/2 per cent. The combined error due to vibration, temperature, altitude, humidity, and other environmental conditions should not exceed about 1/2 per cent if careful design is employed.

In view of the above errors, little trouble should be experienced in holding the overall system accuracy down to within 2 per cent.

A voltage-fed system is inherently less accurate than the capacitance-fed system since errors in the fuel gaging portions are applied to its input and subsequently amplified. The errors are not directly additive since the tank units are used only once in the system, but the rebalance potentiometer errors are doubled, and an additional error is introduced from the use of the proportioning potentiometer. As a result, the overall error of the voltage-fed system may be expected to be in the order of about 3 per cent.

Speed of Response

Theoretically, since the servo or relay balancing methods described are closed control systems, the static error can be made as small as desired merely by increasing the loop gain. Assuming a system with practically zero response time, the higher the loop gain, the greater the number of cycles of operation in a given period of time. As mentioned previously, in order to assure a maximum pump life it is desirable to keep the cycling rate down to a minimum. This means that there is a practical upper limit to loop gain dictated by pump life.

Another practical upper limit to loop gain is governed by the fuel slosh amplitude. Because of turbulence, vibration, wind conditions, etc., a certain amount of fuel slosh exists in every aircraft. Although fuel tanks are usually baffled to minimize slosh amplitude and the capacitive tank units provide further baffling, there still exist small changes in sensing element capacitance due to fuel slosh. If the control system loop gain is made too high the pumps will be cycling as a result of fuel slosh.

In addition to the use of mechanical baffling to overcome pump cycling caused by fuel slosh, various electrical means have been devised to achieve the same effect of which the following two are currently in use:

Method 1

As soon as the bridge unbalance becomes great enough to energize the relay, an additional pair of contacts on the relay armature introduces a voltage in the bridge circuit which unbalances the bridge in the same direction by an amount greater than that caused by fuel slosh. In other words, in order to pull the system out of the slosh region, a static error greater than that due to the fuel slosh is introduced. Thus, pump cycling caused by fuel slosh is reduced at the expense of static accuracy.

Method 2

Even though the slosh rate is in the main aperiodic, it may be represented by a band of frequency components the lowest of which is governed by the definition of fuel slosh. If the c.g. control system contains an integrating network, it can be made to respond only to those frequencies that are below the lowest slosh frequency encountered. Thus, pump cycling caused by fuel slosh is reduced at no sacrifice in static accuracy but at the expense of dynamic accuracy.

A comparison of methods 1 and 2 reveals that insofar as static accuracy (such as obtains in level flight) is concerned, method 2 is much superior to method 1. Under dynamic conditions (as would be caused by pitch, roll, rapid fuel consumption, etc.), if in both cases the system sensitivity is adjusted on the threshold of fuel slosh response, both methods yield the same accuracy.

System Requirements

The decision on whether to use a voltage-fed system or a capacitance-fed system depends to a large extent upon the design of the aircraft fuel gaging installation. For instance, in relatively small aircraft where there is only one fuel gage indicator, the tank units in all the tanks are connected in parallel so that the total capacitance presented to the fuel gage servosystem represents the total weight of fuel in the aircraft. In such an installation it would be both impractical and uneconomical to install a voltage-fed balancing system, since it would require a complete servosystem for each group of tanks used in the balancing system. These two servos would feed a third servo the output signal of which would drive an indicator that would read total fuel poundage. In addition, the former two servos would contain proportioning potentiometers used as adjacent legs in the balancing amplifier bridge circuit.

The addition of the two servosystems to the aircraft would increase the total system weight and complexity,

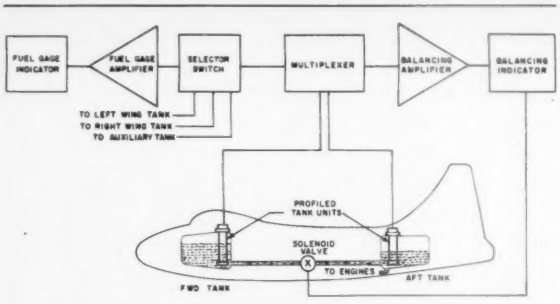


FIG. 3. Combined capacitance fuel quantity gage and c.g. control system.

would roughly double the cost since it would double the number of required servosystems, and would result in a less accurate fuel gaging system since it would require the cascading of servos.

The use of separate tank units in those tanks that form part of the balancing system (capacitance-fed system) would eliminate the need for two extra servos but would also complicate the design of the tanks.

In some installations there may be no room to insert an extra set of tank probes for the balancing function. In this case, the use of time-sharing or multiplexing, (described in the next section) results in the lightest, cheapest, and most accurate of all the systems just described.

The use of a voltage-fed balancing system is indicated in those installations where there are separate fuel gage indicators for each tank on the aircraft. It is then only necessary to alter the fuel gaging system by incorporating an extra potentiometer section in those indicators corresponding to the tanks used for balancing in order to accomplish the desired result. In this case there is then virtually no increase in total system weight and only a slight increase in total system cost. Although the accuracy of the voltage-fed system is somewhat less than that of a capacitance-fed system, it is still an advantage to use the voltage-fed system in this particular installation since it eliminates the need for extra tank probes or multiplexing and represents the simplest modification to the existing fuel gage system.

In some installations a selector switch is used in conjunction with a single indicator fuel gage system to enable the pilot to read the amount of fuel in each tank, in groups of tanks, or in all the tanks. In this case, the use of multiplexing will prove to be the most advantageous.

DESCRIPTION OF A PRACTICAL SYSTEM

Fig. 3 shows in block diagram form a practical c.g. control system that was designed and mass produced by Avien, Inc., and is currently in service on military aircraft.

In this particular aircraft, the forward tank feeds the aft tank through a solenoid valve, and the aft tank feeds the engines. There are three other tanks in the aircraft (not shown) the centroids of which are approximately in line with the c.g. Since the moment arm for each of these tanks has essentially zero length, the moment is approximately zero regardless of the amount of fuel in the tank. However, since the forward and aft tanks have moment arms of appreciable length they contribute greatly toward the total moment about the c.g., and hence automatic balancing is employed as shown.

A novel feature of this design enables the same tank units in the forward and aft tanks to be used for both fuel gaging and fuel balancing. In this arrangement, a multiplexer is employed which switches the tank units periodically between the gaging and balancing systems with a period much smaller than the response time of each system, thus introducing negligible error. The use of multiplexing not only reduces the weight and cost of the system by eliminating the need for two extra tank units but also results in a greater system accuracy since it eliminates the compounding of errors that would result from the use of proportioning potentiometers in the fuel gage indicators. In this particular aircraft, since a single indicator fuel gage system is used, the use of proportioning potentiometers would require the installation of two additional servosystems used for balancing, the outputs of which would be added by the fuel gage servosystem, as previously discussed. This would be expensive, would increase the complexity of the fuel gage system, and would decrease the accuracy of both fuel gaging and balancing systems.

The selector switch connects the fuel gaging system to the tank units in various combinations so that the pilot may read the weight of fuel in each tank, in groups (such as in both wing tanks), or in all tanks at once.

Both fuel gage and balancing amplifiers are three-stage resistance coupled amplifiers stabilized by the use of local feedback to eliminate errors caused by tube aging and environmental conditions.

Both indicators of Fig. 3 contain servomotors, gear trains, and rebalance potentiometers as in conventional positional servosystems. The fuel gage indicator contains both a drum-type counter and a pointer, the counter reading total fuel poundage and the pointer reading individual tank fuel poundage. The balancing indicator is a zero-center instrument that shows the direction and degree of unbalance and contains limit switches—settable to operate at fixed moments of unbalance—which provide a valve-opening signal or a valve-

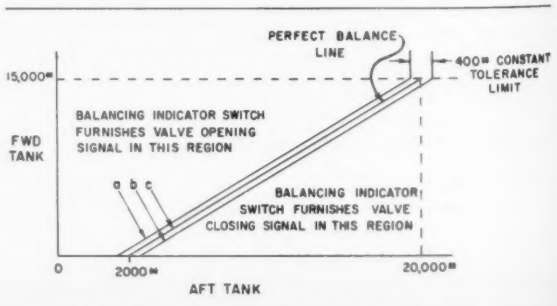


FIG. 4. Operating envelope, typical c.g. control system.

closing signal, depending upon the direction of unbalance as shown in Fig. 4.

When the forward and aft tanks have poundages corresponding to a point on line C, the aircraft is in balance, potentiometer R_3 is at electrical zero (see Fig. 5), no voltage appears at the input to amplifier A, servomotor M is stationary, and the balancing indicator reads zero unbalance. When the aft tank fuel level decreases, tank unit capacitance C_1 decreases, the bridge unbalances, a voltage in phase with V_2 appears at the input to amplifier A, and motor M simultaneously drives the indicator pointer counterclockwise and the rebalance potentiometer arm toward V_1 picking off a voltage equal to the initial unbalance voltage.

When the aft tank level drops an amount corresponding to approximately 200 lbs., a limit switch at point a furnishes a 28-volt d.c. signal that opens the solenoid valve and permits the flow of fuel from the forward to the aft tank. While the fuel is flowing between tanks, capacitance C_1 is increasing, C_2 is decreasing, and the indicator pointer is rotating clockwise. When it reaches point b (which is at approximately +200 lbs.), another limit switch furnishes a 28-volt d.c. signal that closes the solenoid valve, preventing further unbalance in this direction.

Referring to Fig. 4, lines a and b, which are displaced from line C by approximately ±200 aft lbs., represent the respective loci of operation of the limit switches which are shown as a and b of Fig. 5.

It will be noted that the aircraft is balanced when the forward tank is empty and the aft tank contains 2,000 lbs. of fuel. This is the tare that was discussed previously. It represents a linear translation of the balance line C from the origin and is accounted for in the schematic diagram of Fig. 5 by capacitor C_3. In a similar manner, numerous fixed loads such as bombs or rockets could be simulated by fixed capacitors, each connected to the appropriate voltage tap through switches in the bomb or rocket bay so that, as each projectile is fired, a switch disconnects the corresponding capacitor from the bridge circuit, maintaining aircraft balance.

Capacitor C_5 (Fig. 5) is used as a bridge load in order to make the bridge output voltage in phase with either V_1 or V_2 and also to swamp out the capacitance of the shielded cables that connect each tank unit to the balancing amplifier. This effectively renders the system immune to changes in calibration with shielded cable length.

Integration as described under "Speed of Response, Method 2" is designed into the system by the proper

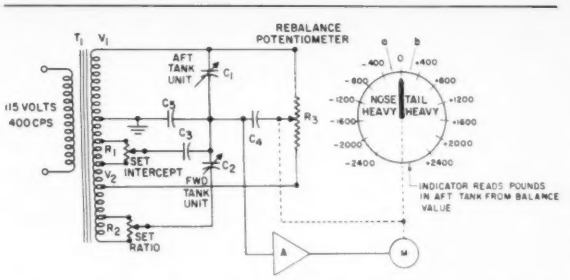


FIG. 5. Practical c.g. control system, simplified schematic.

choice of gear ratio between the motor and indicator pointer.

Although the block diagram of Fig. 3 shows separate amplifiers and indicators, various versions of the system have been constructed where the amplifier and indicator are housed in the same hermetically sealed package. The same diagram also shows individual tank units corresponding to the respective tanks for simplicity of explanation. In the actual installation, however, more than one tank unit is inserted in each tank, and these are connected in parallel, forming electrically a single variable capacitor corresponding to the particular tank. This is done in order to correct for variations in aircraft attitude.

C.G. Control in Missiles

The use of automatic c.g. control for high-performance aircraft suggests application of identical principles to the control of missiles and rockets. Until recently, one obstacle to such application has been the unavailability of tank units suitable for use with oxidizing agents such as fuming nitric acid, hydrogen peroxide, and liquid oxygen which are used with such fuels as hydrazine, ammonia, aniline, and JP-4 as rocket propellants.

The latest tank unit designs developed by Avien, Inc., for fuel management systems employ lightweight plastic tubing, with profiling achieved by means of conductive films with continuously variable contour which are silk screened onto the tubing. The units are encapsulated in transparent plastic of extreme chemical and physical stability.

The development of this type of unit has opened the way to gaging and automatic control of fuels other than the conventional aircraft types. Further application of miniaturization techniques and the use of high-temperature components should result in c.g. control instrumentation ideally suited to rockets, missiles, and pilotless aircraft.

A discussion of how the temperatures and shock waves encountered at high speeds interfere with camera equipment and how to solve these problems by a redesign of the aircraft interior and the camera windows.

Requirements of Military Aircraft Design for Aerial Photography

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REQUIREMENTS OF military aircraft design for aerial photography have, over the past 36 years, been of great concern to me. From World War I until I retired in 1952, the butchering of military aircraft, principally fighters and bombers, was always one of my jobs in the Air Force. There have been one or two exceptions to this when during World War II we designed and constructed special reconnaissance aircraft such as the Hughes Twin Boom-F11 and the Republic Rainbow and more recently, although not originally designed for the purpose, the RB-47.

It has always been my belief that military aircraft should be especially designed and constructed for the tactical and strategic requirements of the Air Forces. The reconnaissance mission is just as specialized as the fighter, bombardment, transport, or any other mission. As a matter of fact, it is the most difficult, and when the need for a special reconnaissance aircraft is fully realized and we design and build this aircraft leaving out the dual bomber and fighter idea, it will result in greatly increased efficiency in accomplishing the reconnaissance mission. This idea is difficult to sell because few reconnaissance specialists have filtered into command positions in the Air Force. Some day I hope this will happen because the need for special reconnaissance aircraft becomes more urgent in an atomic age.

The idea is also difficult to sell because the results of reconnaissance missions are more intangible than those of bombers or fighters. You can see and feel the results of guns and bombs, but the intelligence derived from reconnaissance can be appreciated only by the intellect.

This aircraft need not have the qualities of a fighter or a bomber. It certainly should not lug around heavy structural members designed to support rockets, machine guns, bombs, and the many other things necessary for the accomplishment of fighter and bomber missions. The modern reconnaissance aircraft—especially for strategic reconnaissance—should have superior performance especially in altitude and ranges, and we do have some capable and experienced reconnaissance personnel in the Air Force who could monitor the design of such aircraft. It is unfortunate that the great majority of our American aircraft designers who have devoted their time mainly to the development of fighters, bombers, transports, etc., do not fully understand the requirements that should be incorporated in an efficient reconnaissance aircraft.

This is further emphasized by the new reconnaissance collection equipment being phased into the USAF inventory. In the past several years, many new items used for electronic signal interception (ferret reconnaissance), high resolution radar reconnaissance, infra red, TV, etc., have been successfully tested and are ready for operational use. All of these new types of reconnaissance equipment imposed common design requirements on new aircraft.

In tactical reconnaissance there is a similar need for specialized aircraft. We lost a considerable number of reconnaissance aircraft in Korea. Armor protection covering vital parts of the aircraft could have saved many of these airplanes. The Air Force lost one of its best reconnaissance officers, Col. Karl Polifka, on a low reconnaissance mission because of a fatal fire that it is believed armor protection under his remodeled fighter aircraft could have avoided.

At the same time that we are developing high-performance reconnaissance aircraft we must also work toward improvement in the operational efficiency of our cameras and related equipment. The least the Air Force can do is to give our flying personnel equipment that will function 100 per cent. The hazardous reconnaissance flights involve flying thousands of miles into enemy territory, and every mission, as far as possible, must be a positive operation since in

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* Director, Camera Division.

most cases it cannot be reflown because of weather or other conditions.

The laws relating to general procurement regulations are issued in the interest of all of us; however, their strict interpretation relating to procurement of highly accurate cameras requiring high precision manufacturing, for use in reconnaissance aircraft that have cost millions of dollars, is not in the interest of any of us. We must buy the best, no matter what the size of the business.

The reconnaissance problem has changed basically from what it was at the time of and before World War II. Three major factors have caused this change:

(a) The fire power was tremendously increased by nuclear weapons.

(b) The Iron Curtain came into being.

(c) The operation of strategic and tactical Air Forces is required in areas where common means of orientation (maps) are not sufficiently available.

Increased fire power reduces the amount of detail required about targets. However, it shifts completely the emphasis that was formerly placed upon various types of targets at the time of World War II. Such targets as industrial complexes, traffic systems, populations, and even armies on the ground become secondary with respect to those targets that are capable of delivering nuclear weapons (Counter SAC). These must be destroyed first, and every possibility of striking must be concentrated upon them in order to secure our survival. During World War II, it was not a difficult matter to drop or send agents into enemy territory to obtain pictures and other kinds of information. Distances were not great, and the geographic location of the various countries—some neutral and others supporting a large underground—made it relatively easy; in most cases the information could be obtained promptly. In a war with Russia it would be extremely difficult to obtain information in this manner because of the great distances involved and the geographic location of the important targets in that country. It is common knowledge that most of the new Russian industries are being located back of the Ural Mountains, and we can rest assured they will be well camouflaged or placed underground.

The Iron Curtain deprives us of conventional sources of information and requires that aerial reconnaissance furnish types of information that were not subject to reconnaissance before or during World War II. At that time, the location of all major targets was known in advance and the main task of reconnaissance consisted of furnishing detail for the proper selection of fire power (formation and ammunition) for the strike. Today, the ammunition and formation are fixed factors (single nuclear bomb and single flying aircraft), but the targets to be destroyed are unknown as to location. This situation requires the operation of extensive search activity with the objective of finding and locating the targets that represent a threat to our survival. The task of finding these all-important targets requires extensive use of photography. No chances can be taken by using radar for their identification because radar cannot furnish the required resolution to guarantee detection, and detection must be guaranteed. There is a possibility that someday radar and other means may be sufficiently developed to accomplish this work, but I believe it is a long way off, at least to the time that we can have the equal of the resolution now obtained by photographic means.

The requirements for the operation of air forces over areas where conventional maps are not sufficiently available necessitate that reconnaissance furnish an operational substitute for maps. There is no hope for producing conventional maps of these areas in time for operations because the production of conventional maps supposes two things that are not available—time and a fairly dense ground survey. Maps, in the past, have been the basis for all coordinated military operations. Maps have represented a method for tieing points together over large distances and for describing targets in a commonly usable and understandable form by means of coordinates. They also enabled the determination and distribution of any target location that was identified to the operational units. These operational features must be achieved without maps in order to make air operations possible for we must give the operational people the required description. Reconnaissance must therefore solve the problem of operational substitution for maps, which has not been the case in the past. This is essentially a problem of furnishing guidance or navigational data to any point of the area and of a common reference system that ties the area together and permits the description of any point in a commonly understandable form, permitting the usual communication between various echelons of command. This part of the reconnaissance problem which provides guidance and navigational data to targets can be advantageously solved by the use of radar recordings that are collected along a tight system of parallel programed flight lines similar to those used for target search.

The solution of the new reconnaissance problem requires that different technical parameters be emphasized. Reconnaissance aircraft must be equipped today to perform programed flight lines within certain tolerances without using references to the ground. Radar equipment must be of considerably better geometric quality than it was in the past because its main purpose is to provide the required operational background. Photographic equipment must be of better quality than before because reconnaissance aircraft will be flying at least twice as high without being able to carry longer focal length cameras, except in special cases. Heretofore, we have generally had sufficient space in reconnaissance aircraft. Now and in the future, aircraft will be getting smaller in size and have much larger fill factors, more fuel, and less space for reconnaissance equipment.

Exact control of fast aircraft at extremely high altitudes requires fast response of autopilot systems. This causes high angular velocities of motion requiring

stabilization of camera equipment and radar antennas for high resolution radars. Specific technical problems arise from high-speed flying; Mach Numbers beyond 1, and particularly above 2 and 3, create temperature, turbulence shock wave, and electromagnetic radiation problems that require a large amount of research and development work to be performed to arrive at required solutions. Actually, you can go so fast that the shock wave at the nose of the aircraft starts radiating not only in the heat region but all over the spectrum which would seriously impair radar and photographic operation. This is a problem that should receive considerable attention and effort. It also bears out my contention that we must educate a few of our leading aircraft designers to the many difficult problems entering the reconnaissance picture in this age of high aircraft speeds.

It is believed the high-temperature and shock-wave problems might be solved only by entirely rearranging the design of the interior of the aircraft. Cameras and radar antennas may have to be removed from nose positions in high-speed aircraft and be placed at more favorable locations not yet known, reducing the effect of phenomena of supersonic and hyposonic flight beyond Mach 10.

Operational problems complicate further the general picture of requirements for reconnaissance. In order to collect the necessary information the reconnaissance aircraft must be able to remain on a programed flight or pass over the target. It cannot use offset operation as a bomber can, staying away from defended areas, using a high-speed missile for the last heavily defended stretch. A bomber can operate that way only if the reconnaissance vehicle has first collected the required information providing the offset data. The reconnaissance vehicle must be capable of performance that permits the penetration of defenses of any kind with a reasonable rate of attrition. This must be achieved by higher speed and/or higher possible altitude of operation.

It is obvious that programed flight line operation that may become the basic scheme of future reconnaissance lends itself to being performed equally well by manned aircraft as by missiles. In reconnaissance the missile must be capable of conveying the collected information back to a reconnaissance base. Long-range communication, particularly for the transfer of images, is still a problem in itself and will always be susceptible to interference. It is not, and for some time to come will not be, capable of high resolution. Therefore, it is necessary that reconnaissance missiles have longer ranges than bomber missiles. At least the reconnaissance package must be recoverable to make the collected information useful.

The technical and operational factors determining the scheme and scope of future reconnaissance may well justify the development of a special reconnaissance vehicle to perform reconnaissance for the purpose of identifying, locating, and destroying those all important targets that threaten directly our survival.

For the benefit of the aircraft designers, I consider it advisable to mention or stress again the most important problems confronting the aircraft companies that may be requested to design and construct the reconnaissance aircraft of the future.

One of the most important factors in aerial photography is vibration. Vibration has always been a limiting factor in picture quality, and all efforts must be made to minimize both the vibration of the overall aircraft rolling, pitching, and yawing and the high-frequency air-frame vibration imparted by the buffering of the air stream by the engines, etc. All these must be minimized in the photo-reconnaissance aircraft design. The cameras also should be built heavy and compact to obtain a mass inertia that will not be upset by the vibration frequencies.

A personal feeling on this is that, in this day and age of ground and air defense guided missiles, it is no longer going to be safe for the bomber or fighter—i.e., modified for reconnaissance—to fly unarmed over a target to sit and take pictures. We now need definitely to move toward special performance aircraft that rely on either speed or altitude at the sacrifice of all other features to provide the reconnaissance function. In this, because it now is just a reconnaissance vehicle, the pilot must be provided with the ability to view targets from the air and to locate precisely the ground areas where his cameras are pointed.

The payoff for all Air Force reconnaissance lies in the informational content of the aerial negatives. In the past, even the normal aircraft vibrations and flight characteristics have degraded the quality of the ground images.

Great strides have been made toward increasing the informational content of the aerial photograph through the development and perfection of gyroscopically stabilized camera mounts. The latest and most effective advance in this field lies in the torquer principle. Through the use of torquer mounts controlled by precise gyroscopes, the rotational movement of the aerial camera due to vibration or roll is restricted to a negligible value. As a result, the reconnaissance value of the photographs has increased manifold, and it is now possible to use slow shutter speeds that extend the operational day of the reconnaissance aircraft by several hours. Besides increasing picture resolution, a stabilized camera mount also provides for vertical photography in spite of aircraft yaw, pitch, and roll. Much work is now in process to improve this condition to a point where maps may be made directly from the negative without rectification.

It would appear that for the most efficient camera mount design, and by efficient I mean lightest and least expensive, close coordination is necessary between camera and mount manufacturers and between aircraft and mount manufacturers. With regard to the camera, such items as the tolerance maintained on the center of gravity position, the type and placement of mounting pads, and general shape and size are closely related to the task of producing a small and lightweight mount. In designing an aircraft such consideration as the window size and location, the position of the ship's structural members, the available room, and the vibration present in the aircraft have much to do with

the design problems involved in producing a camera mount.

At this point I should like to mention a problem that is becoming increasingly more critical with new aircraft designs—namely, "What is happening to the windows in aircraft for pilot visibility?" Visual reconnaissance is recognized as an important means of obtaining intelligence primarily because of its wide-area coverage and speed—speed in obtaining information, speed of interpretation of the information, and speed of dissemination of the intelligence. Aircraft designers, because of performance considerations, are sinking the pilot down into the aircraft and wrapping the practically nonexistent window around him. The result is a poor field of view. This is, of course, opposite to the interest of the observer. A good airplane for visual reconnaissance would have high performance, be able to throttle down and cruise at moderate speeds, and yet have high acceleration at low altitudes and a wide field of view.

Another important factor for the reconnaissance aircraft designers' consideration is the location of the camera windows. It is known that turbulent air in front of the camera window adversely affects image quality, but, if the flow of air is laminar, this effect is minimized. It is believed that a laminar flow can be achieved, if some consideration is given to this problem when the aircraft is being designed, perhaps by the use of a fairing at the fore section of the window or by a boundary-layer control. In any event, if a temperature gradient exists in the laminar flow of air, a thermal wedge results, causing a distortion in the resultant picture of an amount serious enough to disturb the accuracy of mapping photography.

The window itself must be considered as a part of the optical system since it is in the path of the incident light. The window is the one part of the optical system which is most subject to damage and must endure the worst abuse. It must withstand large thermal shocks and high pressure differentials and at the same time not have a deleterious effect on the photographic image quality. It has been determined that the endurance to positive thermal shock—i.e., increasing temperatures—increases with the thickness of the glass, whereas, when the glass is subjected to a negative thermal shock, the endurance decreases with thickness. It is interesting to note also that when a negative thermal shock is applied, the thicker the glass the longer it takes before fracture occurs. Laboratory tests at the Air Force-sponsored Optical Research Laboratory, Boston University, show 9 min. for a 1-in. thick piece of glass with a 320°F. change in a few seconds. By suitable mounting of the edges of the window, the effects of positive thermal shock may be overcome. It has been observed also that any scratches on the glass considerably lower its resistance to thermal shock.

It may be necessary to adopt curved photo windows contoured to satisfy aerodynamic requirements. If this is to be, there must be a much closer coordination between the lens designer, camera manufacturer, and aircraft manufacturers to match the optical air dynamical requirements. Optically flat windows, however, are most desirable, covered with a sliding protective metal shield that is moved out of the way at the time of the camera operation.

Photographic film can tolerate a temperature of 160°F. for 8 hours without incurring objectionable base fog and loss of speed, but, as the temperature increases, the time that it can stay at this temperature is reduced rapidly—for example, 170° for 4 hours, 175° for 3 hours, 182° for 2 hours, and 192° for 1 hour. This limiting factor indicates an additional requirement for temperature control in high-speed aircraft.

Pressure and temperature also have an effect on the focus of serial cameras. The low index of refraction of rarefied air moves the focus closer to the lens, and the shrinkage or expansion of the lens cone (the major temperature effect) causes the focus to shift beyond the film plane or inside the film plane, respectively. An uncorrected camera in free air tends to be approximately in focus at 10,000 ft. At higher altitudes the temperature effect takes over, and at 56,000 ft. the camera can be out of focus by as much as 0.080 in., depending on focal length, lens design, materials used in construction, etc.

The problems mentioned here can only be solved by adequate test facilities. Equipments must be debugged, reliability improved, and design objectives more fully demonstrated during the test of experimental and prototype models in time to reduce the number of costly retrofit and modification programs. Research and development engineers are being forced to make entirely too many "calculated risk" decisions not supported by tests in actual aerial environment and component testing in the appropriate environment (altitude and speed) in time to assure the production of operational high-performance reconnaissance aircraft with reliable equipments.

Reconnaissance test vehicles are urgently needed for carrying equipments to be tested to an environment compatible with that of the tactical vehicle in which it may be used. This environment may be at altitudes of above 60,000 ft. and at speeds above Mach 2.

While my main interest today at the Bulova Research Laboratories is in the development of aerial cameras with 100 per cent performance possibilities, I am still concerned with the development of high-performance reconnaissance aircraft; I hope that the U.S. Air Force will fully recognize the great need and spare neither cost nor time in the research, development, and production of such aircraft. The foremost Air Force reconnaissance operational personnel and the reconnaissance technicians at Wright Field and at Boston University's Physical Research Laboratories should work closely with the aircraft designers in the solution of the problems mentioned in this paper. It can be done, and, if it is worth while to build bombers that can destroy an enemy, it is equally worth while to build reconnaissance craft that will tell us exactly where that enemy may be found.

Examples from the experience of the All-Weather Branch are cited to illustrate how a knowledge of the mechanics of aircraft response to control, automatic pilots, radio aids, and radar references is developed through flight research.

Automatic Feedback Control and All-Weather Flying

Dunstan Graham* and Richard C. Lathrop*
Wright Air Development Center

Introduction

In the lobby of the Sperry Gyroscope Company's plant at Great Neck, N.Y., there is a painting. It shows a smiling Lt. James H. Doolittle seated in the rear cockpit of a Consolidated NY-2 biplane. He has just turned back the hood that covered the cockpit and is receiving the congratulation of bystanders and the check pilot in the front seat—Lt. Benjamin S. Kelsey. The congratulations are well deserved! He has just landed and rolled to a stop after a 15-mile out-and-back flight from Mitchel Field without seeing the ground, the horizon, or the sky!

This was the first public demonstration of blind landing. It was made under the auspices of the Guggenheim Foundation on September 24, 1929, as part of their fog flying experiments of that year. The then new artificial horizon, directional gyro, and an elementary localizer indicator—together with the daring and skill of the pilot—allowed him to accomplish an apparently impossible feat.

Today, 25 years afterward, a completely blind landing is still a stunt or a desperate emergency. Air-line schedules are delayed, and military air missions are cancelled or, too often, become tragedies because of low ceilings and visibilities. Because the weather was below minimums, Patterson Field, Ohio, the home of the Air Force's flight research on weather flying, was *closed* for 46 hours during January, 1954.

There are other vagaries of the weather, such as icing on the aircraft and runways, turbulence in the air or extreme gusts along the ground, and damaging rain or hail, which present a hazard for aircraft operation. The central incompletely solved problem of all-weather flying, however, is the conduct of the aircraft along a stable, controlled, flight path, avoiding other aircraft and leading to a safe landing at the intended destination —without the pilot necessarily seeing outside the cockpit.

This is not to say, however, that nothing has been accomplished for blind flying in the last 25 years. In 1937, Capt. Carl J. Crane, Capt. George N. Holloman, and Raymond Stout experimented with automatic radio navigation and flight control. In August, 1937, they took off from Wright Field in an Air Corps Fokker YC-14, flew to Indianapolis, returned to Dayton, and landed at Wright Field under automatic control. Ten years later on September 21–22, 1947, the All-Weather Flying Division's Douglas C-54 "Robert E. Lee" flew the North Atlantic ocean from Stephenville, Newfoundland, to Brize-Norton, England. No human hand touched the controls from the time the take-off roll started until the landing roll was complete. The selection of courses, radio station, speeds, flaps, gear, position, brakes, etc., was completely automatic. No part of the execution of the planned mission was dependent on visibility from the cockpit. Poor visibility along the route or at the landing field would not have hampered the successful completion of the schedule.

The successes of the radio and automatic control engineers, however, tend to be offset by the "progress" of their brothers, the aeronautical engineers. What seemed a promising blind landing technique in 1937 or 1947 is not adequate for today's high-speed jet-propelled airplanes.[1] It has become imperative to be able to guarantee a successful, expeditious landing on the first approach in spite of weather. This is because of the ravenous fuel consumption of jet engines. Furthermore, a steady increase in wing loadings has steadily increased approach speeds and has made the aircraft far more difficult to control on final approach and in landing. Fig. 1 presents the wing loadings of typical aircraft over the span of aviation's history. The plot does not suggest that wing loadings are about to level off. In fact, since improvements in flaps and the introduction of boundary-layer control may be used only to counteract the effects of thinner wings, it seems likely that approach and landing speeds and radius of

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* All-Weather Branch, Directorate of Flight and All-Weather Testing.

turn (inverse maneuverability) will continue to rise sharply.

Thus, as was the case with Tantalus standing thirsting in a pool of water that receded when he stooped to drink, fulfillment seems almost perpetually beyond reach.

Difficulties in providing guidance and control for blind air terminal feed-in, approach, landing, and taxiing to a continual stream of mixed types of aircraft have perhaps been underrated. The integrated, best efforts of radio, instrument, and aeronautical engineers are still required for the successful synthesis of what is a complex and notably dynamic system. Each type of engineer involved has, it seems, tended to underestimate the problems—particularly the dynamical problems—of the adjacent "box." Thus, for example, some radio engineers have represented the autopilot-airplane combination by a single lag operator. On the other hand, some aeronautical control engineers have assumed that radio beams are perfectly straight and that the beams give proportional error signals without noise.

The last 10 years, however, have witnessed an increase and an exchange of understanding. A large amount of data has been accumulated through flight research. Known experience has been organized in mathematical or statistical models; and a whole new field of control engineering science has grown up.[2]

The Problem

The military or economic value of an aircraft depends on its ability to tranverse a controllable flight path. Precision of control is required for terminal navigation, landing approach, and landing.

Abstractly, the airplane in flight is a velocity vector in space. It has a direction in which it is going and a speed with which it is going there. The time integral of this velocity vector is the flight path. Qualities of an aircraft which tend to make it resist changes in the direction or magnitude of its velocity vector are referred to as *stability*, while the ease and expedition with which the vector may be altered are referred to as the qualities of *control*. Stability makes a steady, unaccelerated flight path possible, and maneuvers are made with control.

The flight path of an aircraft is never stable of itself, and the problems inherent in all-weather flying may be epitomized in three words—*flight path control*. A pilot controls the flight path (with a given amount of power) by controlling the attitude of the aircraft. To do this well requires considerable skill under contact conditions and is difficult, at best, under conditions of low visibility.

The difficulty lies not only in not knowing what the flight path is and in the indirectness of the means of controlling it but also in the fact that the airplane, in its conventional configuration, is not attitude stable. With the usual exception of angle of attack, disturbances in the angles that define the attitude of the airplane may diverge, persist indefinitely, or initiate undamped oscillations. This deficiency is overcome by the pilot but only with unending vigilance and effort.[3]

Stability can be obtained through the use of negative *feedback* coupled with control. Feedback is the principle by which cause and effect systems are self controlled. Information about the effect (or output) is fed back (or returned) to the input and is used to modify the cause. With negative feedback this results in the fact that the output is forced to follow (extremely closely) the input.

The science of information transfer and feedback control has been named "cybernetics" from the Greek word *cyberneter*, which means steersman or pilot. Thus, but for the accident of the classical erudition of Norbert Wiener, this science might have been called "pilotics." The name would then serve to emphasize the fact that the theory of feedback control may be employed to elucidate the problem of flying.

When the pilot is operating in clear air, information about the attitude of his aircraft, its position, and its velocity with respect to objects on the ground is fed back to him through his eyes. His remaining four senses do not and cannot tell him enough to stabilize and control the flight path when visual information is denied him. The success of Doolittle's experiment depended on making visual information on the plane's bank, pitch, heading, rate of turn, altitude, rate of descent, and air speed available again in the form of instrument presentations. Given this, a well-trained and practiced pilot can fly blind and, with visual localizer and glide angle information, can approach and perhaps even land on the runway. Nobody pretends that this is simple,

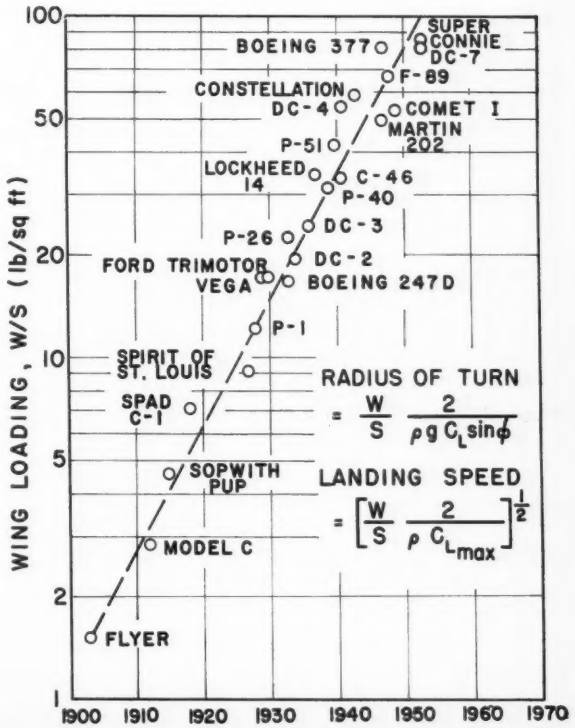

FIG. 1. Wing loading of airplanes.

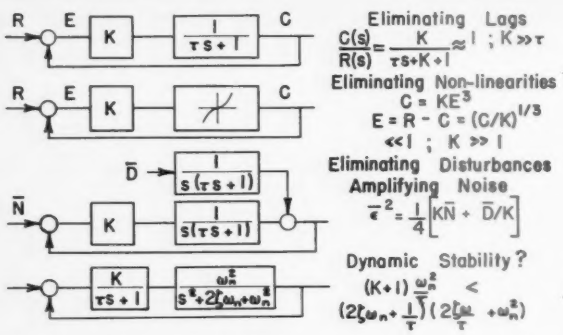

FIG. 2. The advantages and disadvantages of feedback control of dynamic systems.

however, and it seems obvious that the reason is that the amount and quality of the information feedback is less than when the pilot can see the horizon and objects on the ground.

Dynamics of Feedback Control

Automatic feedback control can be used to overcome the limitations of the human pilot who has access only to the limited feedback information available to him on the instrument panel. Typical of automatic feedback control is its speed of response and its accuracy. Also typical, however, is its tendency to hunt or oscillate. The particular advantages of feedback control are enhanced by high *gain*. This is, however, inimical to dynamic stability, especially if time lags are present in the control system. High gain also usually increases the susceptibility of the system to spurious signals or noise. Fig. 2 illustrates symbolically these advantages and disadvantages. Permissible high values of the gain are determined by the system parameters and the qualities of the noise.

Since the human pilot himself represents an equivalent time lag of 0.2–0.5 sec., he is seldom able to operate at "high" gain without instability (over-controlling). For this reason, the pilot is generally unable to achieve the accuracy and speed of response of an automatic system. He represents, however, a remarkable variable-gain amplifier and nonlinear smoothing and predicting filter. He can stabilize and control a wide variety of dynamics. Memory and rational guesswork often play an effective part in deciding his control actions.

Automatic control systems, on the other hand, usually give satisfactory performance only in a narrow range of system parameters. In order to preclude hunting or divergent oscillations it is imperative that the mechanics, particularly the dynamics, of each element in the control loop be understood and suitably taken into account in the system synthesis. Requirements for filtering, compensation, and gain adjustment must be determined before the loop is closed.

Fig. 3 is the block diagram of a simplified aircraft automatic flight path control loop for lateral guidance to a radio beam. For purposes of discussion in accordance with the terminology of feedback control system engineering, the aircraft has been designated the controlled element, the autopilot the controller, and the radio beam and receiver the guidance system.

In subsequent sections each of these elements is treated in turn. Emphasis is placed on the results of flight experimentation as a method of validating existing theories of dynamical performance or of point-

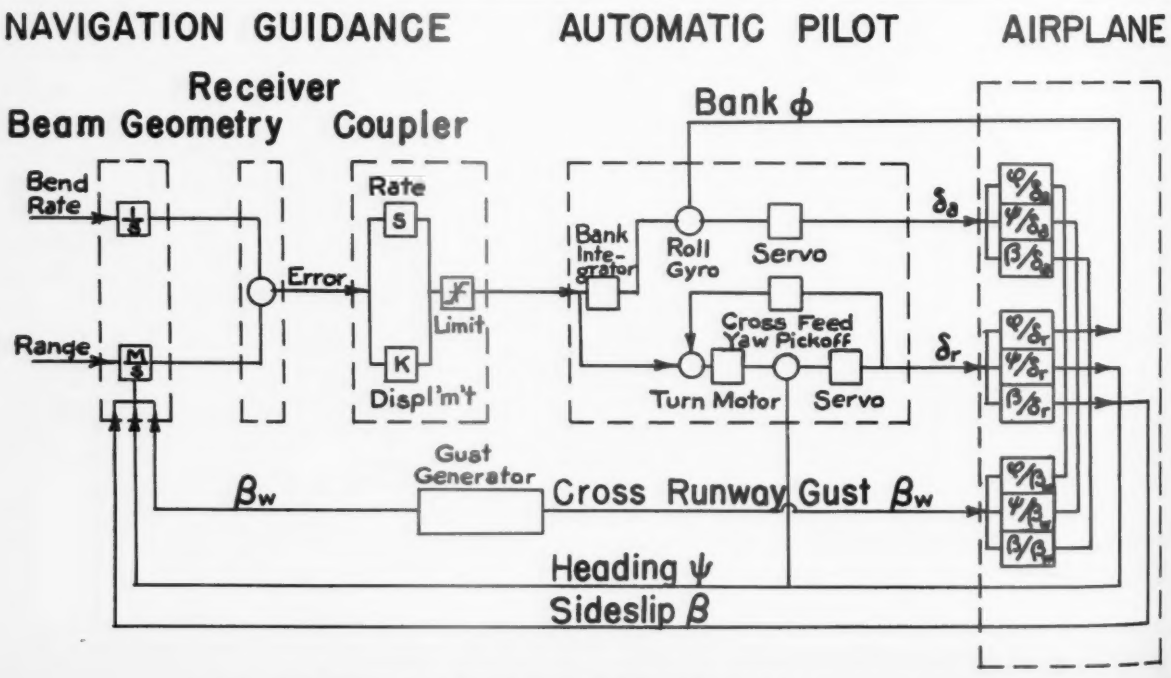

FIG. 3. Block diagram of an aircraft automatic flight-path control loop for lateral guidance.

ing to the need for new analysis. The matching of the various elements in an automatic feedback system for all-weather flying can, of course, be carried out purely by experimental techniques. This is, however, usually extremely wasteful. It is advantageous for the system designer to appreciate the theory and to understand the mathematical or statistical model of each element, even if a complete theoretical analysis is not made.

The Controlled Element: The Aircraft

Design of an automatic feedback control system for an aircraft necessarily begins with a thorough understanding of the inherent mechanics of aircraft response to its controls. The conventional airplane has at least four primary flying controls—ailerons, rudder, elevator, and throttle—which produce forces and moments on the air frame. Actuation of these controls gives rise to motions in the six output variables—roll, pitch, yaw, forward velocity, sideslip, and angle of attack. These combine in modes that may be aperiodic or oscillatory and stable or unstable. When the aircraft is flexible, the further degrees of freedom of the structural modes allow even more complicated response to control.[4]

This intricate dynamical relationship between the inputs to the airplane (control action) and the attitudes and velocities has been investigated in a large number of theoretical and experimental studies.[5]

In spite of this research effort, however, the situation of the automatic control designer confronted with the task of designing a control system for a new aircraft is far from happy. The theory may or may not satisfactorily predict the aircraft's inherent response characteristics. Even in the event that a program of experimental response testing is planned early in the development cycle of the aircraft, the time-consuming problems of tailoring instrument accuracy and sensitivity and the difficulty of data reduction may go a long way toward obviating usefulness of the test.

For these reasons, a continuing effort to develop and validate an adequate theory with experimental evidence and to develop simplified methods of instrumentation, flight testing, and data reduction is still required.

Early in the history of aeronautics a statement of the relationship between the action of the controls and the response of the aircraft was formulated in terms of differential equations.[6] In order to expedite the solution of these equations a number of restrictive, simplifying assumptions were applied:

(1) The aircraft was assumed to be a rigid body.

(2) The mass of the aircraft was assumed to be constant.

(3) All departures from steady, straight-line flight were assumed to be infinitesimally small.

(4) The plane perpendicular to the wings and along the fuselage was assumed to be a plane of symmetry.

(5) With a single exception, the forces and moments on the air frame were assumed to depend only on the instantaneous values of position and velocity of the motion and not on the "history."

It is in this mathematical framework that the dynamic responses of aircraft to control are usually discussed. Assumptions (1) and (4) restrict the number of degrees of freedom which must be considered simultaneously. The others are "linearizing" assumptions that permit the principle of superposition to be applied and allow mathematical treatment to proceed by the relatively simple methods of linear analysis. In particular, they permit the highly developed transfer function approach.

The transfer function is most readily visualized by considering the response of a system to a sinusoidal input. In a linear system, the steady-state output will be a sinusoid of the same frequency but, in general, shifted in phase and changed in amplitude. The amplitude ratio and phase angle between the input and output as a function of frequency define the transfer function. Alternatively, the transfer function may be obtained by dividing the Fourier transform of an output time history (transient) by the Fourier transform of the corresponding control input time history (pulse).

Both techniques have been employed in the experimental determination of the mechanics of aircraft response to controls.[7, 8] Each has advantages and disadvantages. The advantages of the sinusoidal method are:

(1) Ease of data reduction.

(2) More points can be obtained where definition of a rapidly changing functional value is required.

(3) Good definition at low frequencies is possible.

The disadvantages are:

(1) A great deal of time is required to obtain and record the steady-state oscillation.

(2) An automatic control is required in order to obtain a good wave form.

Converse statements describe the disadvantages and advantages of the pulse method. The sweep frequency method that combines some of the best features of both the sinusoidal and pulse methods has been investigated and applied to aircraft-automatic pilot response by Simonton.[9]

In 1951 Milliken, in a paper read before the Third International Joint Conference of the Royal Aeronautical Society and the Institute of the Aeronautical Sciences,[10] ably summarized the then existing state of the aircraft dynamic response testing art. He pointed out that, under favorable conditions, steady-state oscillation and transient input flight methods could be used to yield equivalent and repeatable response data. At the same time, he called for further experience and refinement of methods, particularly for the extension of testing to higher Mach Numbers and into the domain of bending frequencies of the airplane.

Fig. 4 makes a typical comparison between rigid body theory and response data obtained by Wener and Ritchey of the All-Weather Branch from flight tests of the B-47 airplane.[11] It may be observed that theory and experiment do not agree closely. The curves in the vicinity of the short-period peak can be made to correspond by modification of the wind-tunnel values of the lift curve slope and pitching moment due to elevator

deflection. The agreement between sinusoidal and pulse method data is good at low frequencies.

At higher frequencies there is considerable scatter in the points taken from transient data. This "scatter" is not entirely random. It is often periodic with frequency and sometimes is repeatable. Its cause apparently lies in the fact that a velocity limit of the hydraulic power control actuator installed in this airplane inhibits the excitation of appreciable amplitudes of aircraft response at the higher frequencies. (The success of the pulse method is critically dependent on the insertion of a transient input of the correct form containing a broad band of frequencies.) A part of the discrepancy may possibly be attributable to improper fitting of the necessary analytical approximations to the experimental transient data points and to round-off, truncation, or other errors in the complex computation process.

Resonances are identified by a peak in the amplitude response curve. The presence of a peak in the experimental curve at the frequency of primary wing bending indicates that the B-47 in high-speed flight cannot reasonably be considered to be (even approximately) a rigid body. This fact is much more vividly illustrated in Fig. 5, which presents the aircraft response to elevator control as measured at three different locations. If all the parts of the airplane were rigidly connected, the pitching velocity due to elevator deflection would be the same in all parts of the aircraft. It may be seen that this is not even remotely the case. The response at the tail grows larger with frequency while the response at the c.g. is attenuated. The practical implication of this is that locations for sensing and feedback control elements, such as gyros, accelerometers, and control position transmitters, must be chosen with great care in order to avoid possibly catastrophic instability. No satisfactory method has been found for predicting theoretically that part of the B-47 aircraft's response to control which is due to its flexibility.

Another characteristic of aircraft response which may lead to difficulty in attempting to design satisfactory automatic controls is the extremely wide variability of aircraft response with flight condition. The human pilot, for instance, by necessity uses small control movements at high speed and much larger ones in landing. This variability of response leads to a requirement for "gain changing" in aircraft automatic controls.

Figs. 6a and b illustrate the variation of the F-86E fighter airplane's response to rudder control as a function of altitude at constant Mach Number and as a function of Mach Number at constant altitude. The degree of damping of oscillatory motions (indicated by the broadness of the peaks) decreases (in this case) with altitude and for some Mach Numbers. Note that the testing has been carried to $M = 0.9$, well into the transonic regime where the theory of stability derivatives tends to become inadequate. The poor damping and high frequency of oscillatory motions at high speed and altitude have made modern aircraft difficult to control satisfactorily.

There is evidence from some flight tests that, strictly speaking, the lateral and longitudinal modes of motion often cannot be separated and that responses are sometimes definitely nonlinearly dependent on the amplitude or sense of the input, even for "small" inputs. This is not to say, however, that the linear, rigid-body theory is useless. It is usually capable of predicting the main features of aircraft response in the frequency range of interest. Modified and refined as necessary—on the basis of an increasing amount of experimental evidence—to include possibly the primary structural modes, major nonstationary flow effects, and better estimates of transonic stability derivatives, it will permit the design of successful aircraft automatic controls of higher and higher performance.

The situation with regard to rotary-wing aircraft is not nearly so favorable. Experimental evidence with which to compare various theories of helicopter dynamic response to control is meager. This is particularly true of the transient blade motions that are suspected of having an important influence on the response of the helicopter body and flight path.

In attempts to develop a theory, the restriction of analyses to a relatively small number of degrees of freedom does not appear to have much merit. Fig. 7 makes a comparison between two experimental lateral responses of the H-19 helicopter with and without automatic stabilization.[12] Without stabilization, the lateral attitudes and the flight path are unstable. With automatic stabilization in pitch only, the attitudes and path become dynamically stable! Roll and heading stabilization do not, however, appreciably improve the dynamic response in pitch. This demonstrates a complicated coupling between lateral and longitudinal motions.

Another area in which the present understanding of the mechanics of aircraft response to control may prove deficient is in regard to high-speed ground handling characteristics. A considerable degree of success has attended trials of automatic nosewheel steering on a straight radio course.[13] On the other hand, the relative effectiveness of nosewheel steering, differential braking, and aerodynamic controls, and the effects of tire and strut deflection, center of gravity location, runway surface friction, and the optimum combination remain to be discovered. An agressive theoretical and experimental attack, at present under way, should yield the knowledge required for the integration of the landed airplane into an automatic runway and taxiway guidance system.

The principal features of the dynamic response of the uncontrolled airplane, in flight, which are usually successfully predicted by the available linearized-rigid-body-theory and which are often quite apparent to the airplane pilot are:

(1) The poorly damped longitudinal "phugoid" oscillation.

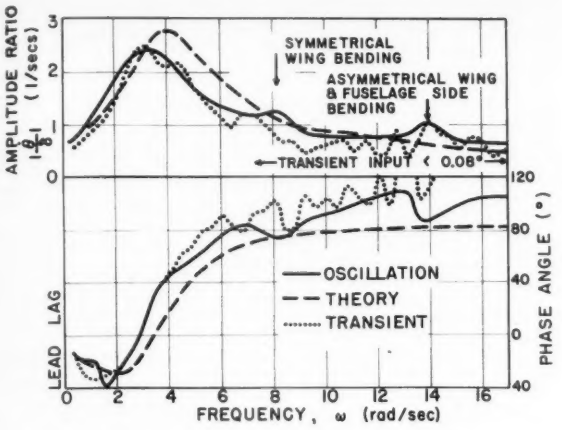

FIG. 4. Theoretical and experimental longitudinal frequency response of the B-47 aircraft: altitude = 20,000 ft., true air speed = 550 m.p.h.

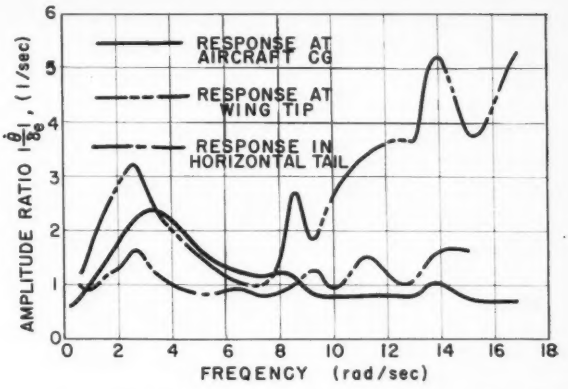

FIG. 5. Longitudinal frequency response of the B-47 aircraft measured at three different locations: altitude = 20,000 ft., true air speed = 550 m.p.h.

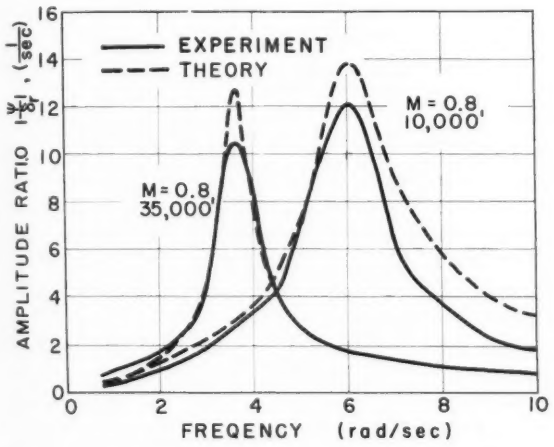

FIG. 6a. The effect of altitude upon the lateral frequency response of the F-86E aircraft, with constant Mach Numbers.

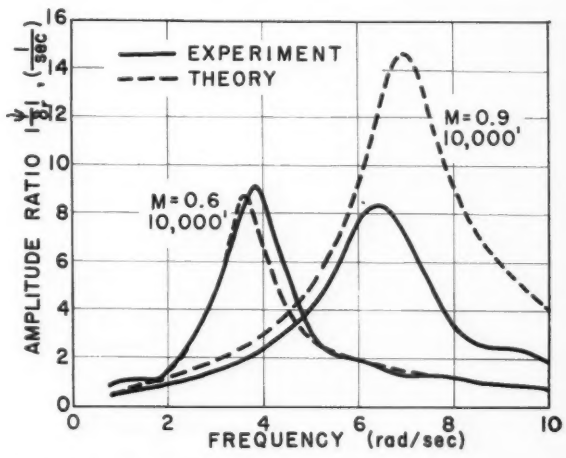

FIG. 6b. The effect of Mach Number upon the lateral frequency response of the F-86E aircraft, at constant altitude.

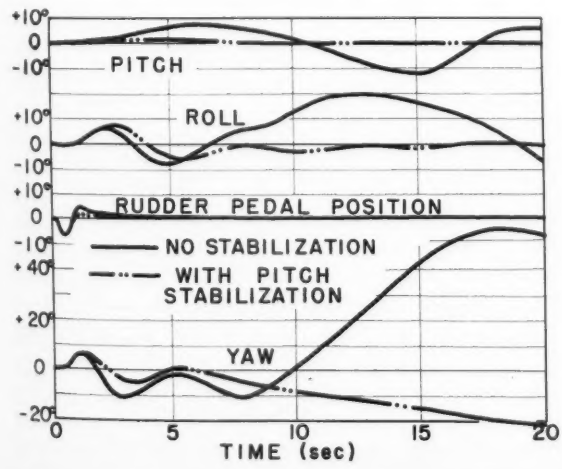

FIG. 7. The effect of pitch altitude stabilization upon the response of the H-19 helicopter to a rudder pulse: altitude = 3,500 ft., indicated air speed = 46 m.p.h.

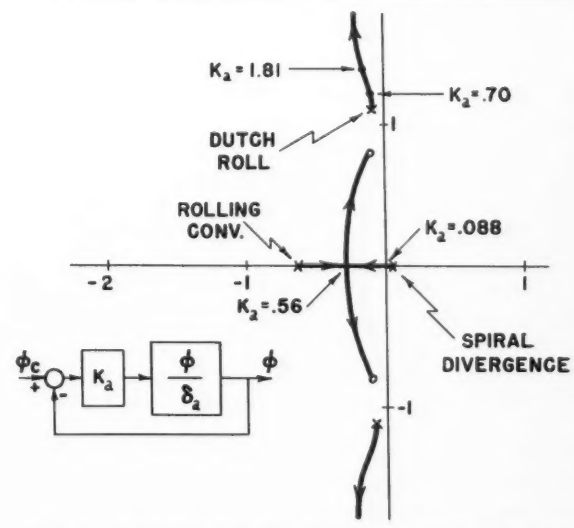

FIG. 8. Root-locus plot of ideal displacement control of the roll axis of the B-47 aircraft. The B-47 transfer function was computed for the following flight conditions: weight = 100,000 lbs., altitude = 10,000 ft., true air speed = 175 m.p.h., Mach Number = 0.24, gear and flaps down.

(2) A possibly poorly damped longitudinal "short-period" oscillation.

(3) A "spiral divergence" at low to moderate indicated air speeds.

(4) The poorly damped "dutch roll" oscillation.

(5) Neutral stability in heading.

The first objective of any automatic pilot design is the repair of these deficiencies.

The Controller: The Automatic Pilot

Prior to 1942, most automatic pilots were used only for pilot relief to allow the pilot to read maps and perform similar tasks with assurance that the aircraft would continue to fly right-side-up on approximately a constant heading and at a constant altitude. Only the simplest maneuvers, such as minor heading corrections, were normally made with the automatic pilot engaged. If an automatic pilot was installed at all, it was usually disengaged during the execution of the more precise phases of flying, such as take-off, bombing runs, formation flying, approach, and landing.

Since that time, most of the effort in automatic pilot development (other than that directed toward improved components) has been concentrated in three areas:

(1) Better stabilization techniques.

(2) Increased capability for maneuvering and for manual inputs.

(3) Increased capability for tie-in to other systems.

Stabilization is the basic function of any automatic pilot. The increase in weather flying, considerations associated with passenger comfort, and weapon delivery have placed increasingly stringent requirements upon aircraft stability. While keeping pace with tremendous increases in performance, designers have often found it too difficult to provide adequate stability by aerodynamic means alone. More and more, the automatic pilot and other stability-augmenting devices are being designed into aircraft as necessary components. Indeed, it may be that some future aircraft will be practically unflyable in certain phases of flight without stability-augmenting equipment.

These requirements have led to the addition or substitution of more elaborate reference systems based upon accelerometers, rate gyros, or a stable platform. In each case, a dynamic stabilization problem was involved.[14]

Effort in the manual input area has provided the pilot with the ability to maneuver the aircraft conveniently with the automatic pilot engaged, thereby retaining the stabilizing functions during the maneuver and at the same time introducing effective control. Some of the earlier devices for this purpose were auxiliary sticks ("formation sticks") and pedestal control units with pitch and turn command knobs. More recently, there has been a growing trend toward the use of the regular pilot's controls to introduce automatic pilot commands. The so-called force stick (or force wheel) has been successfully demonstrated with several different types of automatic pilot.

The technique of tying other systems into the automatic pilot came into widespread use during World War II when a method was developed for automatically steering aircraft on high-altitude bomb runs with signals from the bombsight. A refined version of this device is still in use today. Another example of automatic pilot tie-in is the approach coupler, which will be discussed in more detail later in the paper.

The Displacement Automatic Pilot

An early form of automatic pilot which is still widely used in refined form is the so-called displacement type.[15] Although individual designs vary somewhat in detail, the basic idea is that signals proportional to pitch angle and roll angle are sensed by a vertical gyro and compared with the desired (or commanded) pitch and roll-angle signals. The differences—i.e., pitch error and roll error—are used to produce proportional displacements of the elevator and ailerons, respectively, in such a way as to reduce the errors. Similarly, an aircraft heading signal is developed by a directional gyro and is applied to the rudder. Actual displacements of the aircraft's controls are produced by electric or hydraulic servoactuators.

With a displacement automatic pilot, climbs or dives are performed by an appropriate adjustment of the commanded pitch-angle signal. Turns are made by introducing the desired bank-angle command and simultaneously rotating the heading reference at a proportional rate. For moderate bank angles and for one particular true air speed, this arrangement results in coordinated turns.

A number of refinements have more recently been incorporated into displacement automatic pilots. Attitude-rate signals are usually added to the displacement signals to assist in maintaining stability with "tighter" control. Special sideslip sensing techniques may be employed in the turn control to assist in maintaining adequate coordination over a wide range of bank angles and true air speeds. Automatic elevator trim may be provided by sensing some measure of average elevator force and slowly driving the trim tab to reduce the average force. A barometric sensing element may be added to the pitch axis to cause the aircraft to fly at a constant selected pressure altitude.

The theoretical capability of a displacement automatic pilot for stabilizing the roll axis of an aircraft is illustrated in Fig. 8. In this figure, the loci of the roots of the lateral characteristic equation of the B-47 aircraft are plotted as functions of the aileron control gearing K_a (which is simply the number of units of aileron deflection per unit of roll-angle error). It is assumed that there is no dynamic lag associated with the positioning of the ailerons. It can be seen that even a small amount of displacement feedback—i.e., a low value of control gearing—causes the spiral mode to converge and increases the time constant of the rolling convergence. On the other hand, the effect of low or moderate control gearing upon the "dutch roll" oscillation is negligible. It appears, therefore, that in a

displacement-type automatic pilot the principal stabilizing function of the aileron control system is to keep the spiral mode convergent, and the damping of the dutch-roll mode is left to the rudder control system.

The performance of the pitch axis of an idealized displacement automatic pilot is shown in Fig. 9. In this case, the roots of the longitudinal characteristic equation of the B-47 bomber are plotted as functions of the elevator control gearing K_e (units of elevator deflection per unit of pitch-angle error). Again, an ideal control surface actuator is assumed. It should be noted that a moderate value of control gearing (about 0.5) produces a dramatic increase in the damping of the phugoid, accompanied by a slight decrease in the damping of the short-period pitching oscillation. Since, in most cases, the short-period mode is moderately well damped, aerodynamically, this latter effect is usually not serious. In any event, the damping of the short period can be improved, if necessary, by using pitch rate as an additional feedback.

Fig. 10 is an actual flight test recording of the longitudinal response of the B-47 aircraft with its standard displacement-type automatic pilot, the Sperry A-12D. The disturbance, shown in the top line, is a pulse of 2 sec. duration introduced into the automatic pilot amplifier. Although this recording was made with a system considerably more complex than the simple idealized displacement automatic pilot, nevertheless the general results of Fig. 9 apply. It is possible to discern, in Fig. 10, both the stabilized short period (about 4 sec.) and the stabilized phugoid (period of about 40 sec.), each with a moderate amount of damping.

The vertical gyro used as the reference for pitch and roll in the displacement-type automatic pilot has an appreciable threshold. This threshold, together with the gyro erection mode, can couple with the phugoid oscillation so that the full theoretical benefits of pitch-angle stabilization are not achieved in practice. Lack of "tight" attitude control is most evident at high altitude and on final approach.

A disadvantage of displacement automatic pilots is that the attitude gyros will operate properly only through a limited range, usually not more than $\pm 85°$ from level flight. This imposes a maneuvering limitation that may be unacceptable for fighter-type aircraft.

In spite of this disadvantage, displacement automatic pilots have been extensively developed and are in widespread use today. They are notably successful in stabilizing and controlling passenger, cargo, and bomber aircraft.

Rate Automatic Pilots

Another, and more recent, philosophy of automatic pilot design is based upon a reference system that uses attitude-rate, rather than attitude itself, as the primary stabilizing signal about each axis. Such a system utilizes three mutually perpendicular rate gyroscopes that generate signals proportional to yawing, rolling, and pitching rates. These signals are compared with the commanded rate signals, and the differences are used to deflect the control surfaces in such a way as to reduce undesired aircraft motions.

At least two techniques for commanding turns with rate-type automatic pilots have been devised. In one system, the rate-of-turn command is applied to the rudder, and the ailerons are pulsed to produce the approximate required bank angle. During the turn a lateral acceleration signal is applied to the ailerons to reduce sideslip.[16, 17] In another system, yaw-rate error is applied to the ailerons, and coordination is achieved by applying a sideslip or lateral acceleration signal to the rudder.

Long-term references such as altitude-rate and heading are used, usually at relatively low gain, to assist in maintaining the desired flight path.

The theoretical effect of an ideal rate automatic pilot on the yaw axis of the F-94C aircraft is illustrated in Fig. 11, which shows the influence of the rudder control gearing K_r—i.e., the degrees of rudder deflection per degree per second of yaw rate—upon the roots of the lateral characteristic equation. For the flight condition shown, theory indicates that the aircraft has a divergent "dutch-roll" oscillation and a convergent spiral mode. The dutch roll becomes stable as K_r is increased to 0.18 and is moderately well damped for a K_r of about unity. The beneficial effects upon the dutch roll of yaw-rate feedback to rudder has been repeatedly verified by flight test.

The degeneration of the rolling and spiral convergences into a well-damped oscillatory mode is of academic interest only, and this effect would be greatly modified by the aileron channel of the automatic pilot.

The response to a sudden turn command of an F-94C aircraft with a Westinghouse W3A rate-type automatic pilot is shown in Fig. 12. This figure was made from actual flight-test recordings. The initial damping of the dutch roll by the rudder may be seen; but, after several cycles, the correction signal apparently falls below the threshold level of the rudder actuator, and, from that point on, the lack of aerodynamic damping of the dutch roll is evident.

Fig. 13 illustrates the theoretical effect of pitch-rate feedback to elevator on the F-94C aircraft. It can be seen that a value of K_e (the elevator control gearing) in the neighborhood of unity results in a substantial increase in the damping and natural frequency of the short-period longitudinal mode but does not materially affect the phugoid. The addition of some other reference, such as altitude control, is usually required to damp the phugoid mode adequately.

The theoretical effect of a rate automatic pilot upon the short-period mode is confirmed by flight-test results. Fig. 14 shows the longitudinal frequency response of the F-94C aircraft with and without pitch-rate feedback. The increased damping of the short-period mode with the automatic pilot engaged is evidenced by the flattening of the sharp peak.

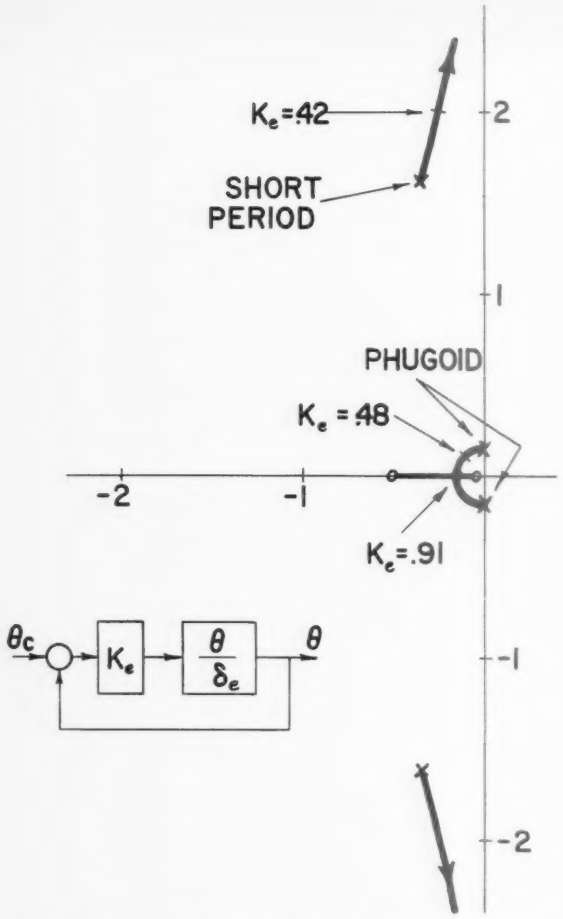

FIG. 9. Root-locus plot of ideal displacement control of the pitch axis of the B-47 aircraft. The B-47 transfer function was computed for the following flight conditions: weight = 115,000 lbs., altitude = 35,000 ft., true air speed = 475 m.p.h., Mach Number = 0.72.

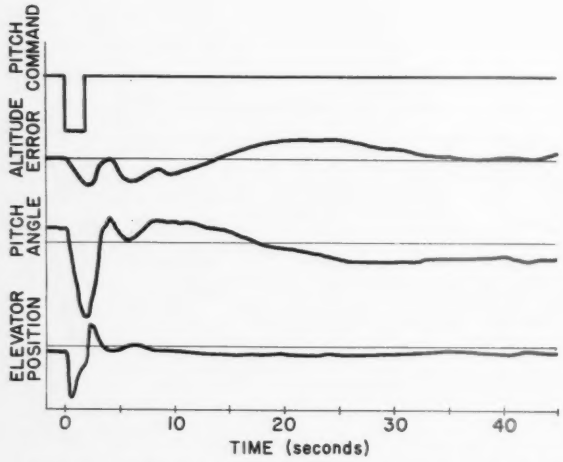

FIG. 10. Flight-test transient response in pitch of the B-47 aircraft with A-12D displacement automatic pilot and with altitude control engaged. The response was excited by a pitch command pulse of 2 sec. duration. Flight conditions were: weight = 121,000 lbs., altitude = 40,000 ft., true air speed = 515 m.p.h., Mach Number = 0.77.

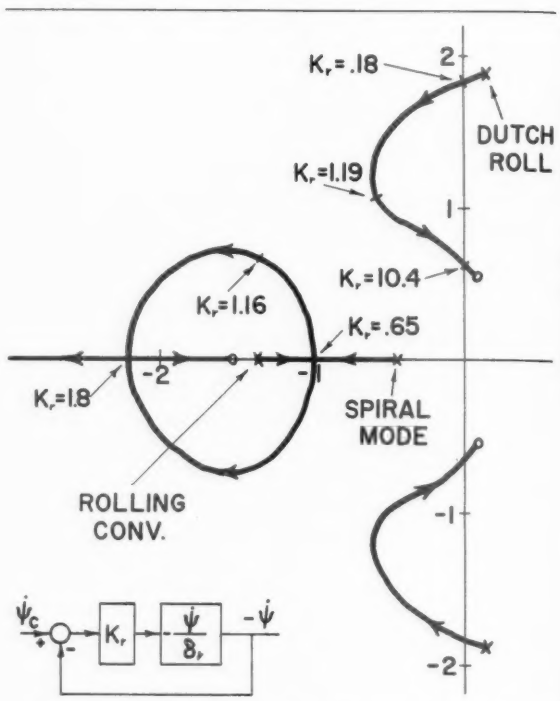

FIG. 11. Root-locus plot of ideal rate control about the yaw axis of the F-94C aircraft. The F-94C transfer function was computed for the following flight conditions: weight = 15,721 lbs., altitude = 42,000 ft., true air speed = 500 m.p.h., Mach Number = 0.75.

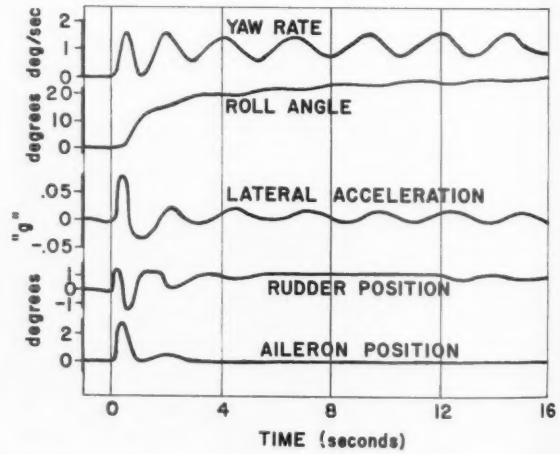

FIG. 12. Flight-test response to a sudden turn command of the F-94C aircraft with W3A rate-type automatic pilot. Flight conditions were: weight = 15,600 lbs., altitude = 35,000 ft., true air speed = 504 m.p.h., Mach Number = 0.8.

Automatic Pilot Problems

Problems associated with very aeroelastic aircraft, such as the B-47, have already been mentioned. Briefly, the additional degrees of freedom usually complicate the stabilization problem, and the location of sensing elements becomes extremely important. The latter statement is also true for rigid aircraft when the sensing elements are far from the center of gravity; significant cross coupling of linear and angular signals can then occur.[18]

With the increase in the speed and altitude capabilities of modern aircraft, it is becoming increasingly difficult to find one set of automatic pilot adjustments which will produce satisfactory results under all flight conditions. Some of the latest automatic pilot designs include provisions for automatically adjusting several gains as functions of Mach Number or some other flight variables.

These effects on the automatic pilot can often be satisfactorily described mathematically. The widespread use of electronic computers to study stabilization, control, and turn coordination—effects of sensing element location and flight condition—leads to an increase of understanding which can be applied to new designs. This is equivalent to broadening and extrapolating flight-test experience.

Response to Gusts

Most of the effort in automatic pilot research and development has been concerned with the response of the aircraft-automatic pilot combination to commanded inputs. Much less attention has been devoted to the response to undesired disturbances, especially gusts, in spite of the fact that the matter is of vital interest in terms of passenger comfort, structural design, rocketry, and precise following of a ground track. The aircraft-automatic pilot combination acts somewhat in the manner of a regulator that tends to follow the reference input (commands) and minimize the effect of external disturbances (turbulence).

It appears that turbulence is a more or less random process that should lend itself well to the statistical techniques developed in connection with the theory of noise. To apply this theory, however, requires a knowledge of the statistical structure of turbulence. Although some work along this line has been done, the actual amount of data on the mathematical description of gusts is meager.

Under contract with the All-Weather Branch, Cornell Aeronautical Laboratory has developed a new technique for the measurement and analysis of flight data which does not require a knowledge of the test aircraft transfer function.[19] It is anticipated that this technique will rapidly lead to a more complete mathematical model of atmospheric turbulence. Fig. 15 presents the power spectral density of vertical gust velocities, obtained from the data of only one test run. It is hoped that more data will be available soon and that the Cornell technique will ultimately lead to a statistical description of the gusts encountered by the airplane which can be applied to the optimum design of aircraft automatic controls.

The Navigation Guidance System: Determining Position and the Velocity Vector

In the preceding two sections the necessity of stabilizing and the means for controlling the aircraft and its flight path have been explored. With these in hand one can turn to the means of defining the desired direction of the velocity vector. Ascertaining the position and velocity vector of the aircraft and determining the heading required to eliminate any difference (error) between the *course* (input) and the *track* (output) is precisely navigation. It can be appreciated, in view of the parenthetical terminology, that naviation is analogous to other problems in control engineering.

While there are a number of possible systems of navigation applicable to aeronautics, those which depend on radio and radar techniques enjoy a pre-emi-

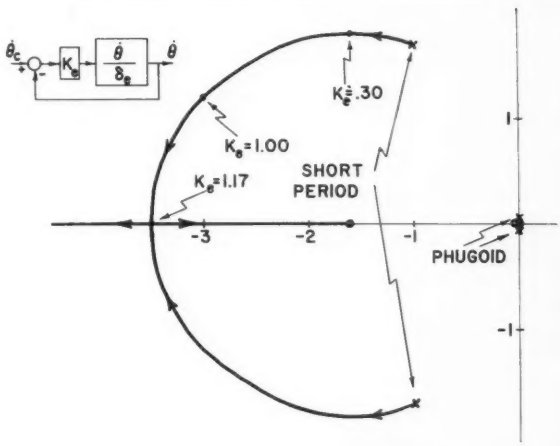

FIG. 13. Root-locus plot of ideal rate control about the pitch axis of the F-94C aircraft. Assumed flight conditions were: weight = 18,900 lbs., altitude = 42,000 ft., true air speed = 500 m.p.h., Mach Number = 0.75.

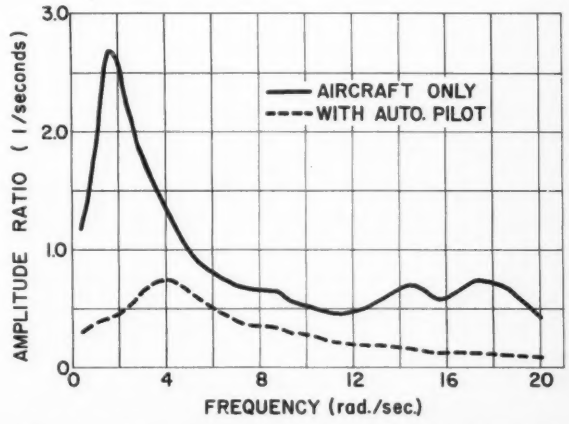

FIG. 14. Frequency response of the pitch axis of the F-94C aircraft, with and without the W3A rate-type automatic pilot. These curves were obtained by Fourier analysis of transient flight-test data.

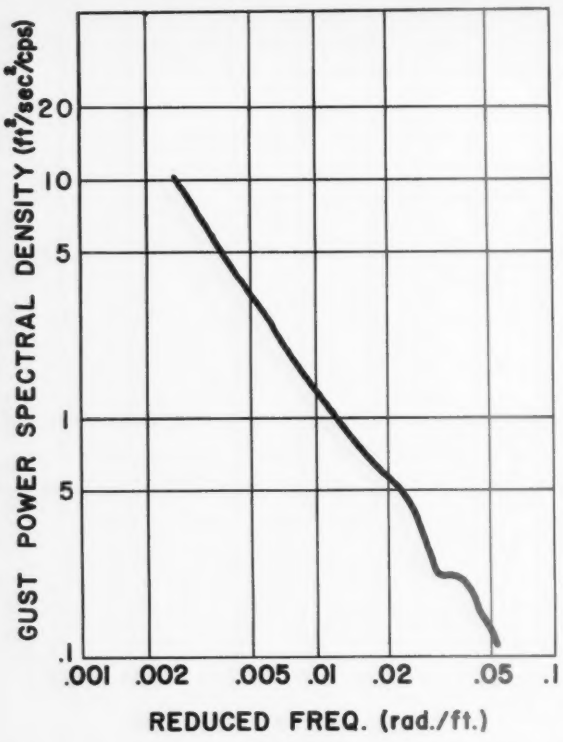

FIG. 15. Power spectral density of the vertical component of atmospheric turbulence.

nent position with regard to blind flying and the automatic control to aircraft. Since it has been found to be both convenient and satisfactory to operate the track control loop (whether manual or automatic) at extremely low gain for en route navigation, no challenging control engineering problems are encountered in that phase of flight. Attention can therefore be concentrated on radio and radar aids for the approach to the runway, landing, and guidance along the runway and taxiways.

Instrument Low-Approach Systems

One of the best known radio aids to navigation is the instrument low-approach system, commonly called ILS for short.[20, 21, 22] Its function is to project into the air, in the form of two radio beams, a "stairway" (the glide slope) and a "banister" (the localizer) which the aircraft, like a small boy in the dark, can follow down to the runway in spite of obscured visibility.

The method of using the beams to make an approach starts with a traffic pattern at an altitude of approximately 1,200 ft. The localizer is intercepted at least 6 nautical miles out and is bracketed so as to reduce the error current from the air-borne receiver and its rate simultaneously to zero. At this point the aircraft's track is on-course. In the vicinity of the outer marker, at 4.5 nautical miles from touch-down, the glide slope is intercepted. The aircraft is placed in the final approach configuration on a descending path, and the glide slope beam is bracketed. The beams are followed by maneuvering the aircraft so as to keep the signals and their rates approximately zero until the aircraft is in a position over the runway from which the landing can be achieved.

In maneuvering the aircraft, if it is simply accelerated toward the beam in proportion to its distance off-course—as if it were constrained to the course with a spring—the system, without damping, would oscillate continuously. For this reason, either the rate of the off-course signal must be used for damping, or some approximation such as the relative angle between the aircraft fuselage and the course must be employed as a measure of the rate of approach to the beam center.

Ideally then, in an airplane equipped with an attitude automatic pilot so that bank and pitch angles are stabilized and controllable, if the bank angle is made proportional to the localizer off-course signal and a certain amount of its time derivative and the pitch angle is made proportional to the glide slope off-course signal, an elementary automatic approach coupling results.

Naturally, due attention must be paid to the adjustment of gains to avoid instability. Since the beams narrow as the transmitters are approached, the effective gains per unit linear displacement from the on-course vary with time during the approach and eventually tend to infinity. For this reason, the gain of the coupling to the localizer is usually stepped down at the time the glide path is engaged, and in some automatic approach couplers it is varied continuously from that point on.

In order to avoid dangerous attitudes the commanded pitch angle is commonly limited to some low value like 5–7° and the commanded bank angle is limited on the final approach to 10–15°. Actuation of the throttles to maintain approximately constant air speed is necessary, but this is often left to the pilot.

A comprehensive computer study by Carroll and Tyler[25] indicated the form of an optimum approach

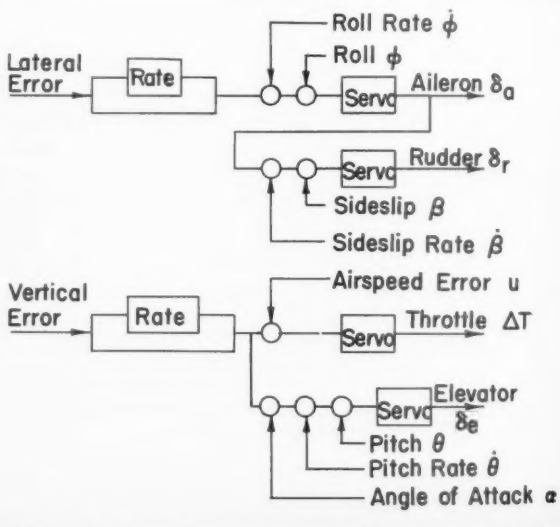

FIG. 16. Optimum linear approach coupler and automatic pilot configuration.

coupling for a linear system with a perfectly smooth beam. The so-called optimum system is illustrated in Fig. 16. Particularly noteworthy features of this system are the feedbacks of angle of attack and angle of sideslip. The rudder is employed only to achieve coordination. There is no heading or heading-rate feedback to either ailerons or rudder. Air speed is controlled automatically with the throttles.

This system has a response to commanded course changes which is slightly superior to any of the other systems that were studied. More importantly, however, it proved to be practically impervious to lateral, longitudinal, and vertical gusts in the sense that these excitations caused negligible disturbances in the flight path.

Susceptibility of the flight path to gusts is a failing of systems that are stabilized to reference angles in pitch and yaw. This failing may be partially overcome by high path loop gain (tight coupling) where considerations of noise and stability do not preclude it.

Relinquishing the heading reference and using the rudder only as a coordination control has been referred to by Anast as "windproofing."[26] Here the aircraft weathercocks into the relative wind and avoids producing the aerodynamic force that would accelerate it away from the desired path.

No quantitative measure of the merit of the complete optimum system has yet been made in flight. Individual features of the system have, however, been flight checked. Directional windproofing, angle of attack stabilization, and automatic air-speed control have all been tried. It seems likely that a complete synthesis of these features will permit a new order of accuracy in automatic approach on the instrument low-approach system.

Automatic air-speed control has particular merit in those jet aircraft where operation at or below the speed

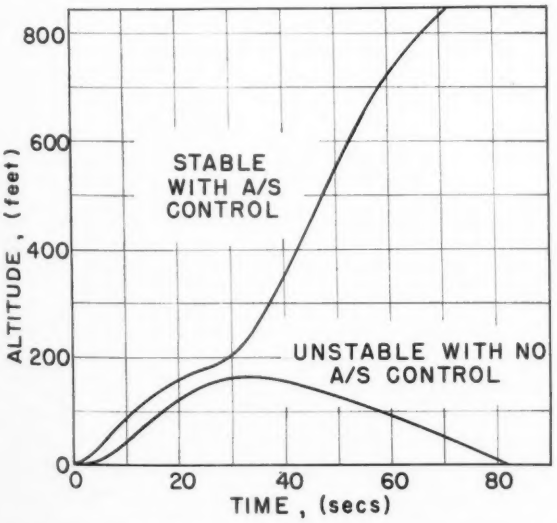

FIG. 17. The effect of automatic air-speed control upon the response to a 4° pitch-up command. These data were obtained by flight test in a T-33 jet trainer with an F-5 displacement automatic pilot. The initial air speed was 120 m.p.h., with gear, flaps, and dive brakes down.

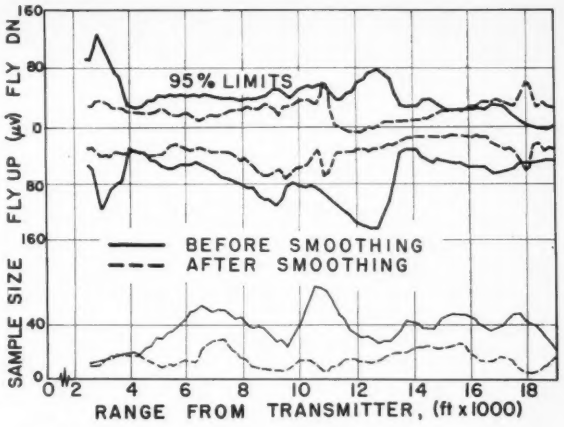

FIG. 18. The effect of terrain smoothing upon the dispersion of received glide-path signals along a constant radial.

for minimum drag is desirable in order to keep the approach speed within reason. This is graphically shown in Fig. 17, which illustrates the unstable case without automatic air-speed control and stable case with automatic air-speed control.

Unfortunately, the picture of a straight, noise-free beam and proportional signals is deceptive. The points at which zero error signal may be read are ideally on the straight line the airplane is supposed to fly at the intersection of the planes defined by the glide path and localizer. However, the zero signal points are, in fact, dispersed.

Slight differences in the levels of the energy fed to the various antennas forming the beams or motion of a reflecting object illuminated with the radio energy cause the "on-course" to shift from time to time. Furthermore, reradiation from buildings, hills, and power lines causes repeatable vagaries in the on-course known as bends.[21, 27] The use of the ground as a reflecting plane makes the straightness of the VHF glide slopes critically dependent on smooth terrain in front of the glide slope transmitter.[28] Fig. 18 illustrates, for example, the dispersion of signals on a constant geometric glide angle before and after smoothing the terrain in front of the transmitter. Any vertically polarized energy in the localizer beam causes the apparent position of the on-course to shift as a function of airplane attitude.[22] Finally, the signal vs. position curve (cross-course sensitivity) is usually nonlinear instead of representing a constant proportionality, and it is possible to observe regions where the on-course doubles back on itself and the sensing is reversed.[21]

Collectively, in accordance with the terminology of control engineering, these spurious signal effects are called noise. As in other control systems, this noise decidedly limits the achievable performance of the automatic approach coupling. Regrettably, all this noise does not fit in any convenient mathematical category, such as stationary random process. Therefore, in the absence of an adequate theory, methods for synthesizing the control loop depend heavily on experi-

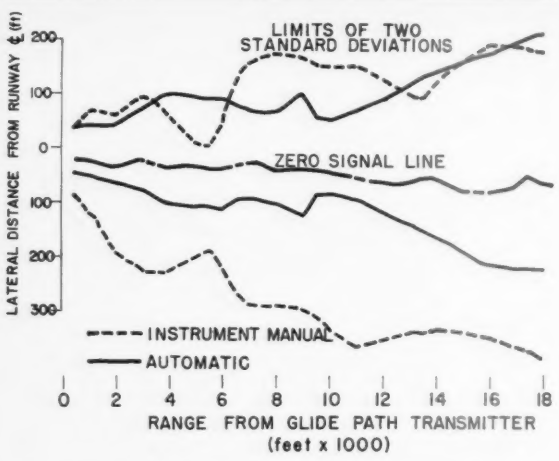

FIG. 19. Comparison of manual and automatic ILS approaches on the CAA standard localizer, showing the limits of two standard deviations about the mean paths.

mental procedures, and the assessment of its performance must be made in terms of probabilities.

If it were possible to produce a localizer and a glide slope whose signals had a negligible amount of noise superposed on them, then the gain or tightness of the path control loop would be limited only by considerations of stability, and the probability of successful automatic approaches would be extremely high. Early results from tests of a 2,600-mc. microwave instrument low-approach system supported this conclusion. The comparison among the microwave automatic, 110-mc. SCS-51 automatic, and SCS-51 manual approaches, illustrated by Anast,[26] shows the approximately geometric improvement in performance on going from manual to automatic approaches and on going from automatic approaches on a mediocre beam to automatic approaches on a very straight one. These results had led at one time to a firm conviction of the merit of automatic approaches and microwave frequencies.

A similarly impressive statistical comparison between automatic and hooded manual approaches on the familiar standard CAA 100-mc. localizer is made in Fig. 19. These data are obtained from phototheodolite tracked approaches. Recent flight-test results, obtained by Captains L. C. Wright and C. P. Thomas of the All-Weather Branch, indicate that the merit of the microwave beams is probably attributable solely to directivity of the radiation and that entirely comparable, perhaps superior, results can be obtained by making localizers in the 100-mc. band highly directive.

More often than not, the selection of a particularly high quality beam system will not be at the disposal of the system designer. In the presence of noise, the track control loop must be derated to avoid resonances, and the necessity for filtering imposes a restriction on the quality of the derivative signal that can be obtained. For these reasons it is desirable to study the stucture of the beam noise, since the noise characteristics will determine the permissible gain and therefore the precision of the track coupling to the radio course.

The All-Weather Branch has recently completed measurements of the "flyability" of six different localizers and six different glide slopes[29] under the auspices of the Air Navigation Development Board. These measurements were taken under controlled and comparable conditions. Data from more than 1,400 measured approaches will be reduced and presented in the form of:

(1) Location and definition of the on-course.
(2) Variation of cross-course sensitivity.
(3) Location of the approach tracks in space.
(4) Average curvature of the tracks at various ranges.
(5) Distribution of aircraft attitudes.
(6) Standard deviation of received signals.

Figs. 18 and 19 are examples of such data.[30] Collectively these data will permit a comparison of competitive radio equipments and methods of coupling on the basis of several figures of merit.

Unfortunately, because of the time-varying nature of the noise, the construction of the beam maps suggested by Mercer[21] for the comparison of instrument low-approach systems has not been considered to be feasible. Furthermore, the extrapolation of data on aircraft position and heading at various ranges to permissible weather minima seems to be based on such tenuous assumptions as to make the labor of constructing his approach success charts unjustifiable. It appears from the All-Weather Branch tests that there is no lower limit to automatic approaches which can be attributed to inaccurate following of modern localizers. Roughness on the glide path below approximately 120 ft. will usually preclude the use of the instrument low-approach system for automatic touch-down landings.

AGCA

Automatic ground-controlled approach (AGCA) is a radar system operationally comparable with the instrument low-approach system. Aircraft position and velocity are observed on the ground, compared with the desired course, and the difference is sent to the aircraft as a control signal via radio link. Since the range to the aircraft is an inherent output of the radar, it can be transmitted for the use of the crew, but, more importantly, it can be used to modify the control signals in such a way that the track loop gain does not increase as the aircraft approaches to land. In this way the optimum adjustment of the track control loop can be maintained throughout the final approach.

At the present time, R. M. Rogers and D. J. Grozewski of the All-Weather Branch are conducting investigations in an attempt to minimize the dynamic problems of the control signal computer. The attempted introduction of a ground-computed rate signal and the extension of the computer passband give rise to amplification of the radar scan-rate noise and to an incompletely explained 1/5-cycle per sec. interference. In

one test, in which the noise and the frequency characteristics of the ground computer, approach coupler, automatic pilot, and aircraft represented an unfavorable combination, the ailerons deflected from stop to stop to synchronism with the 1/5-cycle per sec. interference. Cross talk between azimuth and elevation control signals in the radio data link also appears, at present, to limit the dynamic performance of AGCA.

These limitations do not, however, preclude the accomplishment of successful approaches. Fig. 20 shows the time history of an approach made by a large jet aircraft of the B-47 type with the assistance of AGCA. The standard deviation with respect to the mean path 1,000 ft. from touch-down of 28 B-47 automatic ground-controlled approaches was only 38 ft. in azimuth.

As in the case in connection with the instrument low-approach system, the quality of the information from the AGCA radar deteriorates as the aircraft approaches the ground. In either case some auxiliary source of guidance information must be employed in order to make consistent touch-downs.

Flare-Out and Landing

Over a period of years experiments have been under way employing an FM radio altimeter as the source of vertical guidance in order to accomplish automatic landings. In simplest form the altitude and altitude-rate signals are compared. Any difference represents a departure from the ideal exponential flare-out path and is used as a command signal that causes the airplane-automatic pilot combination to return to the desired path.

Considerations of stability and noise, however, preclude coupling the aircraft-automatic pilot combination with this form of guidance to the flare-out path at the high gain required to avoid appreciable steady-state errors. Both analog computer studies by Porter[31] and subsequent experimental flight tests of equipment designed by Farris[32] have shown that this difficulty may

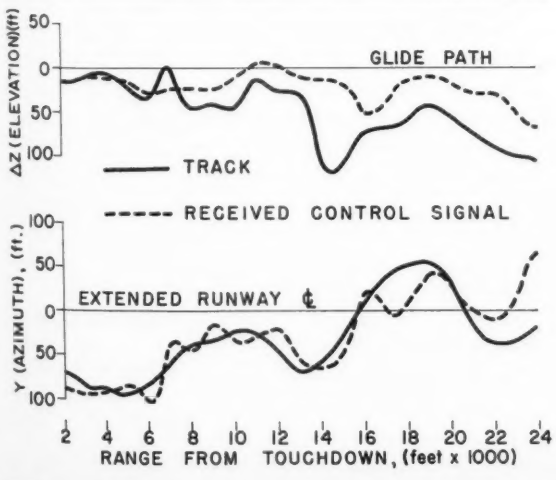

FIG. 20. Time history of an approach by a B-47 jet aircraft with automatic ground-controlled approach (AGCA).

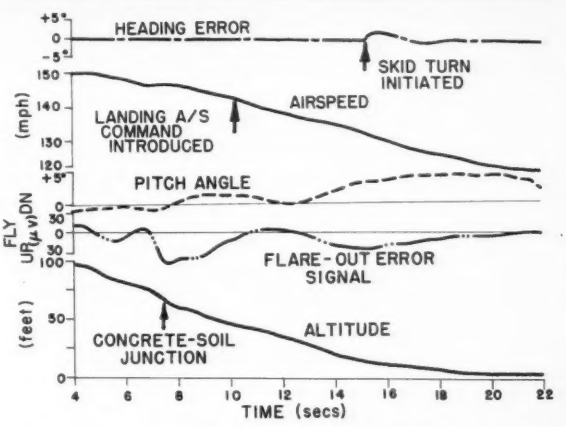

FIG. 21. Time history of an automatic flare-out landing of a T-33 jet aircraft.

be overcome with an application of the principles of combined open-cycle closed-cycle controls.

In a successful automatic flare-out landing system, the reference pitch attitude is programed as a function of altitude. Transition from approach air speed to landing air speed is also programed and controlled automatically. Pitch rate feedback is sometimes required to improve dynamic stability. The difference signal between altitude and altitude rate may then be used at a gain that is high enough to give good control of the path, but which is not so high as to threaten the stability.

Fig. 21 is a time history of a typical automatic flare-out landing of a T-33 jet trainer equipped with a modified APN-22 radio altimeter, All-Weather flare-out computer, and F-5 automatic pilot. The execution of the programed changes in air speed and pitch attitude may be seen from the record. Wings-level crab angle elimination is also carried out on a programed basis. The transient at the concrete-soil junction is due to the differing radar reflection characteristics of the two materials. The transient, however, is well damped. The aircraft actually touched down in approximately a three-point attitude and with zero rate of descent at the instant where the record ends.

Guidance on the Ground

Even without a fog, it is sometimes trying for the human pilot to guide his landed airplane correctly along the runways and taxiways of a large, strange airport. In order to maintain high landing rates in foggy weather, it appears desirable to make provision for the automatic guidance of aircraft on the runways and taxiways. One of the most promising proposals for doing so involves the detection of the magnetic field in the vicinity of a current-carrying wire buried in the runway or taxiway. (This same scheme has, of course, also been proposed for the control of automobiles on highways.)

Preliminary experiments carried out cooperatively between the Radio Corporation of America and the All-Weather Branch on Patterson Field did not meet with complete success. They indicated problems in

obtaining sufficient coverage, in developing a satisfactory rate signal for stabilizing purposes, and in avoiding distortion of the signal due to the presence of iron and other current conductors.

There is no reasonable doubt, however, that these impediments can be overcome and complete automatic all-weather aircraft operation from chock to chock can be a reality.

The Traffic-Control System: Avoiding Collisions

It is one thing to have a single aircraft-equipment combination that is capable of blind landing, and it is another thing entirely to have a ground environment capable of providing guidance for terminal feed-in, approach, landing, and taxiing to a continual stream of mixed types of aircraft. The many aircraft not only must follow the path to the runway but also must be separated in space or time so as to avoid collisions.

A familiar traffic-control system, in use for many years, involves stacking the aircraft over a radio fix with individual altitudes separated by 1,000 ft. For a variety of reasons approximately 500 ft./min. is a preferred rate of descent. Therefore, it takes at least 2 min. for each aircraft to shift its position in the stack, and the landing rate is fundamentally limited to less than one aircraft each 2 min. Every air traveler in bad weather knows as well as the experts that the rate achieved does not suffice for a modern metropolitan airport.

The use of surveillance radar, which is capable of pinpointing the position of all the aircraft within its range, permits a skillful human controller to direct the aircraft safely through an approach gate, along the approach, and onto the runway at a rate of one to two aircraft per minute, depending on the type of aircraft. There is some upper limit, such as six, to the number of aircraft that the individual can simultaneously keep under observation and control. Improved displays and operating procedures show promise of helping the limits.

The process of terminal air traffic control can, however, be made automatic. The number of aircraft under control is then limited only by the amount of equipment available, and the other advantages of speed and accuracy of control are secured at the same time.

In the Volscan system of automatic radar air traffic control, developed by B. F. Greene and his associates at the Air Force Cambridge Research Center, each aircraft is automatically delayed in its arrival at the approach gate by an amount just sufficient to create an orderly flow of aircraft from random arrival on the periphery of the control zone. (The computer has some of the attributes of Maxwell's demon, but this is not yet the key to perpetual motion.)

The delay is introduced by commanding an increment in aircraft heading (relative to the direct path) at each instant proportional to a function of the ratio between the time to go to the desired arrival time and the time required for the aircraft to fly directly to the approach gate. In this way, the control of each aircraft's path is enclosed in a geographically vast feedback loop that operates to null the error in anticipated arrival time smoothly, accurately, and continuously by lengthening or shortening the path to be flown to the gate.

Flight trails, conducted in the vicinity of Clinton County Air Force Base, Wilmington, Ohio, during 1952, permitted the final adjustment of the Volscan computer. Results showed that for a large number and variety of aircraft, the control over time of arrival at the traffic-control gate was precise enough to allow scheduling of mixed types of aircraft for landings at the uniform rate of two per minute! This is approximately the same performance as is achieved through the cooperative efforts of tower operators and pilots under the best conditions of unrestricted visibility.

Conclusion

In early 1952, Anast, reporting to the Institute of the Aeronautical Sciences on progress in automatic flight control, said: "It is possible to control conventional aircraft automatically in most phases of their flights in spite of weather. Exceptions to this are automatic landing and traffic control."[26] Today, consistent automatic flare-out landings and automatic air traffic control have been achieved along with improved performance in the other phases of flight.

These achievements and the control systems that make them possible are built on knowledge of the mechanics of each part of the process which has been gained through flight research. Experimentation with full-scale aircraft has had the effect of confirming some theories and of pointing out the need for new ones. Where theories are incomplete, experimental results provide necessary design data.

Although successful automatic feedback systems for all-weather flight control have been synthesized, the more general problem of synthesizing systems of optimum dynamic performance, cost, and reliability remains for the future. Comprehension of the problems involved, however, has proceeded to the point where the limitations of familiar techniques are recognized in spite of the statistical nature of results and other confusing detail. Designs to overcome or by-pass present limitations can now be undertaken with the assurance of significant results, and the invention of new and better systems will follow.

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An analysis of the pilot's performance of intra- and/or suprasystem functions and the consequences for design of information displays and control systems.

The Human Operator as an Aircraft Systems Component

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Introduction

The requirements of contemporary aircraft systems design raise many questions relating to optimum utilization of human capabilities in man-machine systems. Consistent answers to these general questions must be predicated on a particular philosophy of human utilization. The following observations are representative of one point of view evolved by the author as a working member of a system design team.

By choice, only systems that include one or more human operators will be considered here.

Allocation of Functions

The task of the operator and, therefore, the design of components for his use will depend upon those areas of system responsibility allocated to him. Hence, this assignment of responsibility must be accomplished before either the human factors or component efforts can be appropriately channeled. The allocation of functions has two aspects—assignment of responsibility between man and machine and between man and man.

The weight-space requirements of any air-borne system demand that two criteria of component selection be met: (1) any component should be utilized to its optimum capacity and (2) duplication of components should be avoided except where there is sufficient reason. The human operator is a component already specified for inclusion in the system. If the criteria are to be met, it follows that the automatization of any required function must be justified on the grounds of the operator's inability to perform the function adequately. That this requires a detailed understanding of the operational capabilities of the operator is obvious. It is not sufficient, however, to demonstrate that automatization will result in superior performance. It is necessary to show, in addition, that the system requires this superior performance and that neither weight-space nor system reliability is unduly sacrificed for the increased performance.

Assignment of functions between man and man within the system is primarily a matter of assuring that the work load on any one operator is not sufficiently heavy to cause system breakdown or deterioration of performance below criterion levels in critical situations.

Display Design

The requirements of the operator for information will be determined almost wholly by the function or functions he serves in the system. The display of information that does not contribute to this function may be considered gratuitous and even dangerous to the operation of the system.

The tasks performed by the operator in current systems fall into two broad categories that may be characterized as intrasystem and suprasystem tasks.

As an intrasystem element, the operator may be viewed as a component in a more or less continuous control system in which he serves as the principal detection and control element while the machine provides sensing, power, and actuation. If his function is limited to this form of task, the operator needs only information that will tell him which control to move, when to move it, how much to move it, etc.

As a suprasystem element, the operator serves a monitoring and executive function, providing the flexibility of programing to meet contingencies that are usually lacking in the automatic system elements. It is for the performance of such functions, within the bounds of the component selection criteria stated in the preceding section, that the human operator is uniquely equipped.

It should be clear that the information required by the operator as a suprasystem element differs considerably from that required for intrasystem operation. This difference has led to the distinction between two major classes of information displays. These have been designated by a number of names, among which perhaps the most descriptive are "end-point" displays and "situational" displays.

End-point displays, in essence, define for the operator a performance goal that may be either a geographic point—for example, the runway in the landing situation—or some desired performance condition such as course-to-fly. An end-point *display* characteristically exhibits only the end-point and deviations from conditions which would result in the desired performance (error indication) or control action necessary to achieve

* Biomechanics Unit.

the end-point (command indication). The implementation of end-point displays, then, requires that the *system* "know" (1) the desired end-point or condition, (2) the desired en route program for achieving the end-point, and (3) the instantaneous system performance relative to the above—i.e., the error.

The situational display, in addition to giving the operator end-point information, places the end-point and the aircraft in some frame of reference, the action environment, thus providing not only deviations from some desired program but knowledge of events as they occur—a prerequisite for suprasystem operation.

The relationship between end-point and situational displays will be easy to visualize for those who have attempted to drive through a fog by following the taillights of another car (see Fig. 1). In this situation, the lack of a frame-of-reference renders performance liable to errors in programing. The driver experiences considerable difficulty in maintaining a stable course—he weaves back and forth and may run off the road altogether. Further, he must follow-the-leader since he has no other information. Clear away the fog and the driving problem assumes an entirely different aspect. The driver proceeds easily and steadily along the prescribed course or may select alternatives as they present themselves.

The example of an end-point display given in the preceding paragraph is not fully representative of the utility of this form of indication. With appropriate precomputation the end-point display has certain characteristics that render it an excellent instrument. These have been aptly summarized by F. V. Taylor of the Naval Research Laboratory and are given here. End-point displays provide:

(1) An increase in the number of things an operator can do simultaneously (by combination of parameters into a single indication).

(2) Great precision of response.

(3) A reduction in training time.

(4) A reduction in selection problems.

On the other hand, there is information that the end-point display does *not* provide:

(1) Orientation in the action environment.

(2) Alternative courses of action.

To the extent that the aircraft does not carry its own "automatic" decision devices, the operator must perform suprasystem functions and must have situational information. If, on the other hand, end-point performance with situational display is not sufficiently precise or rapid, some combination of the two forms may be required.

Whereas end-point and situational refer to the *kind* of picture presented to the operator, these do not provide a complete display specification. There is ample evidence that the control-display and performance-display relations within the system are critical determiners of performance. A current viewpoint* groups

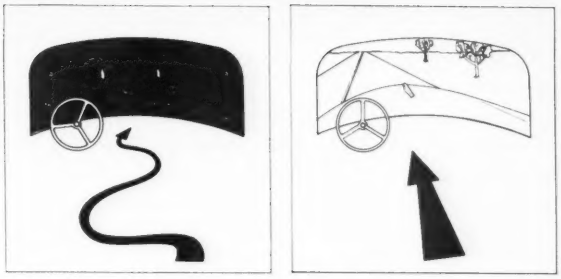

FIG. 1. Diagrammatic stylized representation of end-point and situational displays.

the demands of display dynamics into two general categories. The first requires that the necessity for performing complex interpretive and computational operations be removed from the operator by taking advantage of his natural response propensities, by integration of information parameters, and, where necessary, by precomputation of data. The second category refers to the process of circumvention of the control-performance lags in the system, providing the operator with some degree of immediate knowledge of the eventual results of his control action. Since the goal of both "unburdening" and "quickening" techniques, as these have been termed, is to require of the operator only those functions for which he is best suited, these considerations comprise an important aspect of display design.

Integration of information into a few displays as an unburdening device raises still another display requirement, that of the internal *compatibility* of the items to be integrated. It may be taken as a practical truism that any information so combined should possess a common and appropriate frame of reference. Furthermore, where transition from one source of information to another is required, it is important that no confusion result from incompatibility of reference frameworks.

Finally, on the grounds of the proposition that overloading of the operator's visual channel may be avoided by utilizing auditory or tactual displays, a number of attempts have been made to determine what information is amenable to display by way of these alternative sensory modes. In the case of nonvisual display of spatial information, three difficulties have been encountered:

(1) Ambiguity of input symbols when transformed into nonvisual form.

(2) Too few discriminable states (just noticeable differences) in the nonvisual mode.

(3) Inability of the operator to transform continuous nonvisual information into continuous spatial meanings without a prohibitively long training period.

As a consequence of these difficulties, nonvisual displays would seem to be warranted only for:

(1) Information that is intrinsically nonvisual—e.g., stick "feel," oral communication.

(2) Alerting signals—e.g., target contact, system failure, operational mode change.

* Birmingham, H. P., and Taylor, F. V., *A Human Engineering Approach to the Design of Man-Operated Continuous Control Systems*, NRL Report 4333, April, 1954.

Control System Design

As in the case of the needs of the operator for information, his control requirements will depend largely upon the type of function he is called upon to perform—i.e., whether he is acting as a suprasystem or intrasystem component or some combination thereof. In either case, system design must take into account the characteristics of the operator as a generator of decisions and as an information transducer.

As a decision generator, current theory views the operator as a probability computer, attributing increased likelihood to certain members of a pre-established set of alternatives on the grounds of the information received. To the extent that preprograming is not available, the system must be designed to assist the operator in generating and implementing appropriate decisions. However, most tasks require at least a partially intrasystem role for the operator. For this reason, it is desirable to examine in somewhat greater detail some of the characteristics of the operator which will have a direct influence upon the control system design.

The intrasystem role of the operator as the principal detection and control element has already been mentioned. Attempts to arrive at an accurate transfer function for the operator in this role have unearthed an almost unique fact concerning the operator—*he changes his transfer function to fit the demand of the situation*. This must not be taken to mean that optimization of the man-machine linkage can be to a large extent ignored. This flexibility is not accomplished without effort—effort that may produce overloading in critical situations. Optimal utilization may be achieved by taking advantage of the multifunction characteristic of the operator only when absolutely necessary, utilizing the simplest functions wherever possible.

The simplest transfer function, and the one that appears to be optimum for the operator, is that in which a force proportional to the magnitude of the error is applied. The arguments in support of this hypothesis have been presented in some detail in a recent publication by Birmingham and Taylor.* To consider the operator's output strictly as a force, however, represents a needless refinement—it may, in fact, be inaccurate in some cases. The operator's response to a step-function input, for example, shows a definite ballistic phase of approximately the same duration regardless of the amplitude of correction made. Thus, it may be desirable to approximate the operator's output by the more convenient concept of a sequence of discrete displacements. To the degree that the operator makes corrections of a ballistic nature—i.e., sequential incremental responses—it would be expected that accuracy of performance will suffer when there is any appreciable delay between control action and indication of its result. This is the case with the human operator.

A further functional characteristic of importance which has been argued for the operator is that he is effectively a single-channel sequential computer, performing operations on a time-sharing basis. Protection against overload then requires that, when multiple tasks are to be performed (in effect, simultaneously), no single task requires continuous attention and/or correction.

These operational characteristics impose a set of minimum requirements upon the control system which must be achieved if maximum utilization is to be attained. These are threefold:

(1) The operations required of the operator must be limited to simple amplification or, at most, first-order integration.

(2) Time delay between response and result indication must be minimized.

(3) The responsibility for continuous correction must be removed from the operator.

A number of design techniques are available to meet these requirements.

Simplification of the control function for situations in which the desired end-condition is continuously changing may be achieved by a technique that has become known under the name of *aided tracking*. This arrangement may be considered as an attempt to combine the advantages of positional and higher order control. In idealized form, force applied to the control displaces the controlled member by a corresponding amount and also gives it an increment of the higher order derivatives. For the simple "rate-aid," it involves a feedforward loop, and the linear relationship is given by

$$d\theta/dt = \lambda\,(d\Phi/dt) + \mu\Phi$$

where θ and Φ are the displacement of the controlled member and the control, respectively. We can see, as pointed out by Hick and Bates,† that there are two ways of looking at an aided system. It may be regarded simultaneously as "*basically a velocity control*, but made effectively positional for small corrections, thus reducing its order and making it easier to operate"; or "*basically a positional control*, but with a velocity component added to avoid the necessity for continuous correction."

It should be noted that the effectiveness with which aided control performs within a given system will depend upon the aiding constant, λ/μ, selected. This constant, in turn, has been found to differ within wide limits in different applications and consequently should be empirically determined.

Minimization of the control-display lags in those instances in which they result from processes inherent within the system may be achieved by a variation on the aiding technique. If we schematize a second-order control system, as in Fig. 2(a), it will be seen that, so far as the display-control relation is concerned, aiding *and* partial circumvention of the time delays can be accomplished by feeding-back into the display the earlier-occurring intermediate functions, as shown in Fig. 2(b). In the definitive sense, any *aided* system is

* Birmingham, H. P., and Taylor, F. V., *Ibid.*

† Hick, W. E., and Bates, J. A. R., *The Human Operator of Control Mechanism*, United Kingdom Ministry of Supply. Permanent records of Research and Development, May 30, 1949.

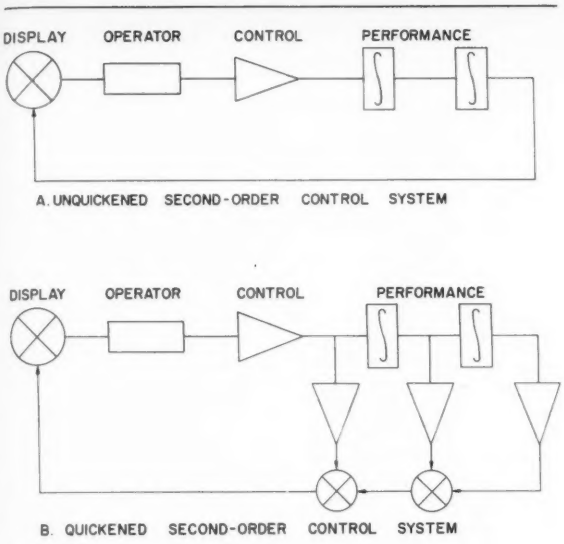

FIG. 2.

quickened; however, the term and the techniques are particularly applicable when the operation is performed upon the display-control loop rather than the control-output loop.

More direct and complete circumvention of the control-display lag may be achieved by use of an extrapolative device that displays, at any instant, the result of a given control action projected to some time in the future. Two forms of prediction devices with regard to aircraft control may be distinguished, those displaying a prediction over some fixed interval of time and those displaying the steady state that will result if the instantaneous control action is maintained. All predictive devices, particularly those that perform their operations upon present performance plus command alone, suffer from the influence of uncontrolled parameters, such as turbulence, to a degree proportional to the interval over which performance is extrapolated.

Once again, within the limits of the automatization criteria, the required complexity of the flight control system will be a function of the overall task allotted the operator. The levels of system complexity may be characterized according to the form of system control responsibility assigned to the operator.

The Decision Operator

To the extent that the operator is a purely supra-system component, all that is required of him is that he indicate to the system the appropriate program to follow. This is essentially a push-button form of operation and requires of the system complete responsibility for execution. Needless to say, few practical aircraft tasks are sufficiently invariant to permit this form of control.

The Spatial Operator

Most systems require that the operator more or less directly implement his own decisions, thereby avoiding the need for a large number of predetermined programs within the system. In systems of this sort, the operator is still largely a decision maker, adding to this function the generation and execution of programs. For aircraft system operation, programing takes place primarily in three co-ordinate space, hence systems appropriate to this form of task provide automatic stabilization of flight so that the operator need exert only primary control. This is one of the functions of autopilots.

The conventional differential-servo autopilot provides the necessary stabilization, aids in making maneuvers, and maintains a flight condition established by the pilot. If we schematize the differential servo as in Fig. 3(a), its operational characteristics will become clear. It should be noted that, for turn, the second derivative of spatial performance (roll rate) is proportional to the control displacement. A system that more nearly approximates the theoretically more desirable direct primary control balances control displacement against the first derivative of performance (bank angle)—see Fig. 3(b).

The Flight Controller

Where the operator is required to perform directly the flight control functions including stabilization, a certain amount of automatization is still required in contemporary aircraft—control boost, yaw damping, etc.—for functions beyond the range of operator capabilities.

It will be seen that as the level of responsibility descends toward intrasystem function, the corresponding load upon the operator increases. One of the problems in the design of an optimum system will be to establish the appropriate balance between component utilization and operator load.

DESIGN LIMITATIONS

Certain practical limitations to system design for optimum operator utilization must be recognized since they set the bounds within which the design must be executed. Most important among the sources of these limits are those imposed by (1) the operational situa-

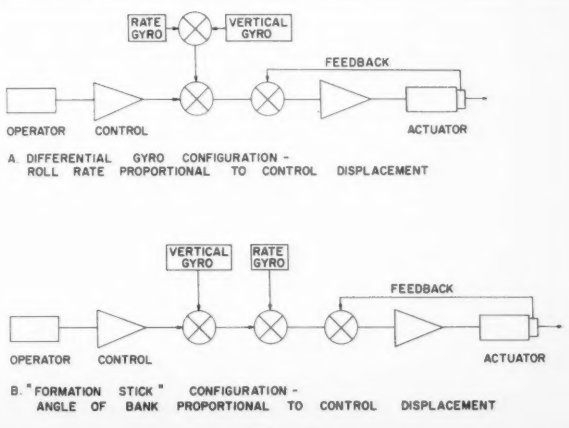

FIG. 3.

tion, (2) the availability of components and techniques, and (3) contractual specifications.

These limits, in most cases, are expressed in the form of component design specifications. Looking at systems design from the viewpoint expressed here, however, will normally necessitate some review, restatement, and refinement of these specifications in order to incorporate the operator requirements into them.

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Smith, J. P., Deputy Chief Designer, The de Havilland Aircraft Co., Ltd.
Still, E., Technical Director, Normalair, Ltd.
Sutcliffe, P. L., Assistant Chief Aerodynamicist, A. V. Roe & Co., Ltd.
Taylor, J. L., Tekniske Hoegskdle, Trondheim, Norway
Templeton, H., Senior Principal Scientific Officer, RAE
Van der Maas, H. J., Professor, Delft Technological University, Holland
Van de Vooren, A. I., Chief of Section for Flutter and Theoretical Research, National Aeronautical Research Institute, Holland
Vessey, H. F., Aero Flight Section, RAE
Waite, J. B., Sales Manager, D. Napier & Son, Ltd.
Waite, P. J., Deputy Division Engineer (Canada), D. Napier & Son, Ltd.
Walker, N. K., in U.S.A.
Walker, P. B., Head of Structures Department, RAE
Walmsley, R. H., Head of A.R.G., Ministry of Transport & Civil Aviation
Ward, R. W., Experimental Designer, Gloster Aircraft Co., Ltd.
Weir, R. H., Principal Director, Engine Research & Development, MOS
Wharton, G. H.
Williams, D. L. Hollis, Technical Director, Westland Aircraft, Ltd.
Willit, A. A. J., Pump Designer, Dowty Equipment of Canada Ltd.
Wimpenny, J. C., Senior Aerodynamicist, Stability Control and Flutter, The de Havilland Aircraft Co., Ltd.
Woodall, R. H., Technical Director, Rotax Limited
Youens, F. P., Advanced Projects Engineer, Short Brothers & Harland Ltd.

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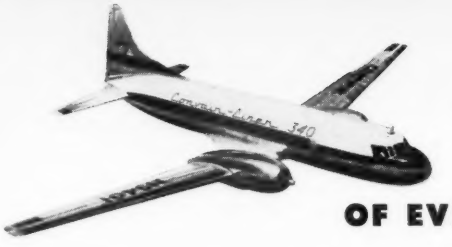

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(*IAS News continued from page 37*)

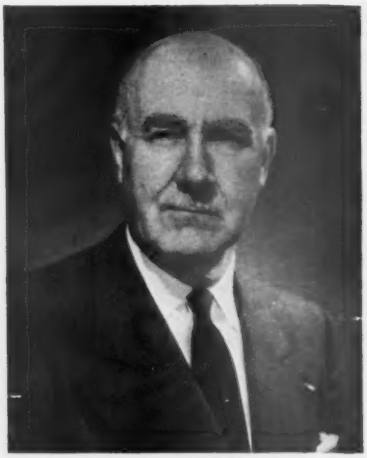
▸ **Theodore von Karman** (HF), Chairman of NATO's Advisory Group for Aeronautical Research and Development, has been elected Honorary President of the Israel Society of Aeronautical Sciences, Tel Aviv, Israel.

▸ **Gill Robb Wilson** (M), Editor and Publisher of *Flying* magazine, has been elected President of the Air Force Association.

Members on the move . . . .

This section provides information concerning the latest affiliations of IAS members. All members are urged to notify the News Editor of changes as soon as they occur.

Leslie E. Neville, MIAS, has been appointed Director of Public Relations and Advertising by American Bosch Arma Corp. He was formerly Director of the Armed Services Technical Information Agency, Department of Defense.



Edward M. Powers, FIAS, has retired as Vice-President of Curtiss-Wright Corp. and resigned from the Board. The former major general, a member of the IAS Council, joined the company shortly after retiring from the Air Force in 1949.

Robert P. Brush (AF), veteran Engineering Test Pilot of Douglas Aircraft Company, Inc., has transferred to the Commercial Sales Division. An air-line pilot before joining Douglas in 1939, he has logged more than 10,000 hours and has participated in flight testing numerous military and commercial planes.

R. Gordon Campbell (M), Assistant Professor of Aeronautical Engineering at Rensselaer Polytechnic Institute, has been appointed Associate Professor of Aeronautical Engineering on the faculty of the new R.P.I. Hartford Graduate Center in Hartford, Conn. United Aircraft Corporation is assisting the program of graduate education for scientists and engineers by providing 17 adjunct professors from its staff.

Milton U. Clauser (AF), former head of the School of Aeronautics of Purdue University, has been named Director of Ramo-Wooldridge Corporation's new Aeronautics Research Laboratory.

Elliot Daland (AF), one of the founders of Piasecki Helicopter Corporation, has joined the Board of Piasecki Aircraft Corporation.

Louis G. Dunn (F) has been promoted to Director of the Guided Missile Research Division of The Ramo-Wooldridge Corporation, Los Angeles.

Colonel Lee V. Gossick, USAF (M) has been named to head the European office of the Air Research and Development Command in Brussels, Belgium. He has been Chief of the Air Defense Systems Division at ARDC headquarters in Baltimore for the past 3 years.

Boone T. Guyton (M) has been named Sales Manager of the Instrument and Systems Division of Norden-Ketay Corporation. Formerly Sales Manager of the Norden Laboratories Corporation, he was one of the first Naval aviators graduated from Pensacola. He has been a test pilot with United Aircraft Corporation and Assistant Sales Manager of Chance Vought Aircraft, Inc.

Rear Admiral Lloyd Harrison, USN (Ret.) (AF), has joined McDonnell Aircraft Corporation as Vice-President—Procurement, in charge of purchasing and subcontracting. He was formerly Deputy and Assistant Chief of the Navy's Bureau of Aeronautics.

Rear Admiral Robert S. Hatcher, USN (Ret.) (AF), has been named Director of the Guggenheim School of Aeronautics at New York University and Chairman of the Department of Aeronautical Engineering. He was formerly Assistant Chief of the Navy's Bureau of Aeronautics, in charge of research and development.

Ephraim M. Howard (AF) is now in the Turbo Jet Facilities Group of Allison Division, General Motors Corporation, as Senior Project Engineer. His duties involve design of test facilities for turbojet engines and engine components. He was formerly Senior Experimental Engineer.

J. Albert Keeneth (AM), of Glen Head, N.Y., has been appointed Eastern Sales Representative by the Aircraft Bolt Corporation of El Monte, Calif.

Donald N. Meyers (M), a mechanical engineer and pilot who participated in developing the Piasecki military helicopters, has been named a director of the newly formed Piasecki Aircraft Corporation.

Lieutenant Colonel Ralph J. Nunziato, USAF (M), who has been Chief of the European office of the Air Research and Development Command since it was opened in 1952, has returned to the United States. Part of the Office of Scientific Research, the ARDC office in Brussels, Belgium, monitors U.S. Air Force research

The U. S. Air Force has honored Grover Loening, FIAS, with its Award for Exceptional Civilian Service. In the office of the Secretary of the Air Force, in Washington, Mr. Loening *(left)* receives the medal from Harold E. Talbott. For the past 2 years, the pioneer airplane designer has served the USAF in an informal scientific and technical capacity as a consultant on research and development.

being conducted by European universities, organizations, and individuals.

Marshall M. Segal (TM) has joined the Worthington Pump and Machinery Corporation, Harrison, N.J., as a Test Engineer in the Research Division. He will continue teaching night classes in mathematics at the Newark College of Engineering.

Hyman Serbin (M) has resigned as Professor of Aeronautical Engineering at Purdue University to take a new post as Assistant to the Director of Scientific Research at Convair, A Division of General Dynamics Corporation, San Diego, Calif.

William M. Shaffer (AM), formerly a junior engineer in the Service Engineering Section of Boeing Airplane Company, Wichita, Kan., has become a technical writer. He is Assistant Editor of the RB47E *Illustrated Parts Breakdown Handbook*.

Werner Spilger (M) has joined Lockheed Aircraft Corporation, Burbank, Calif., as an Instrumentation Engineer "A." He was formerly an Aeronautical Research Engineer in the Technical Analysis Division at Holloman Air Development Center, Holloman AFB, N.M.

Walter P. Targoff (M) has been named Assistant Head of the Aero-Mechanics Department of Cornell Aeronautical Laboratory, Inc. He formerly headed the Applied Mechanics Section and C.A.L.'s diverse flutter research program.

Theodore Theodorsen (F) has been appointed Director of Scientific Research of Republic Aviation Corporation. The former chief of NACA's Physical Research Division has recently been with the Office of Scientific Research of the Air Research and Development Command, USAF, and was a consultant to the Brazilian Air Force and to companies in the aviation field.

Armand J. Thieblot (AF), President of Thieblot Aircraft Company, Inc., of Bethesda, Md., has been elected a Director of Vitro Corporation of America. Vitro recently purchased a 45 per cent stock interest in the company founded in 1951 by the French aircraft designer.

Cyril C. Thompson (AM) has been named airport consultant to the Aircraft Owners and Pilots Association.

Wilmot H. Webb (TM) has joined the Office of Scientific Research, Air Research and Development Command, USAF, Baltimore, as Research Administrator of the Mechanics Division. He was formerly a Research Assistant at Rensselaer Polytechnic Institute.

Robert A. Webster (M) has joined North American Aviation, Inc., as Senior Engineer—Research, in the Preliminary Design Section, Aerophysics Department, Downey, Calif. He was formerly an Aerodynamics Engineer with Ryan Aeronautical Company.

Richard P. White, Jr. (M) has been appointed Head of the Aeroelastic Research Section at Cornell Aeronautical Laboratory, Inc. This is a new section replacing the Applied Mechanics Section.

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we'll build the inverter!

Bendix Red Bank offers you the widest range of aircraft inverters found anywhere. And because each Red Bank inverter is engineered and built as a complete, unified mechanism, it provides maximum operating efficiency on the job it is designed to do.

Over and above current production models, Bendix Red Bank experts develop and manufacture a large number of custom-built inverters for highly specialized applications. For example, in the missile field alone, a wide variety of Red Bank inverters are today giving peak performance under conditions previously thought too severe for dependable operation.

Now under construction are still other specialized inverters designed to meet even more severe environmental conditions.

Out of this unique background has emerged the experience, manpower and facilities that equip Bendix Red Bank to build inverters to fit any specialized needs.

You tell us your need, and we'll build an inverter to handle it. Write today for further information.

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PROGRESS NEEDS PROTECTION

The ruins of ancient Rome proclaim her empire one of the earth's great civilizations. An island of culture in a primitive sea, her people flourished as did art and commerce. But when Rome grew too busy to protect her progress, the barbarians smashed her cities and broke her glory.

Let us glance then at this past as we face a golden age of progress. For the past often mirrors the future. Knowing Grumman's past, for instance, is a reason the Navy depends on Grumman for the future.

In Grumman's twenty-five year past are the Wildcats and Hellcats of task force fame. With them Grumman broke aircraft production records. With them the Navy and Marines shot down two-thirds of the enemy planes destroyed in the Pacific Theater during World War II. In Grumman's more recent past are the Panthers, the first Navy jets to fight in Korea, and the three Cougars that flew coast to coast in 3 hours, 45 minutes, 30 seconds.

But this past is only a base for Grumman's research and brainpower to provide future progress in protection.

At right, model of F11F-1 Tiger fired by rocket to determine drag characteristics by latest research method.

Photograph at left courtesy Italian State Tourist Office

* * * *

GRUMMAN AIRCRAFT ENGINEERING CORPORATION

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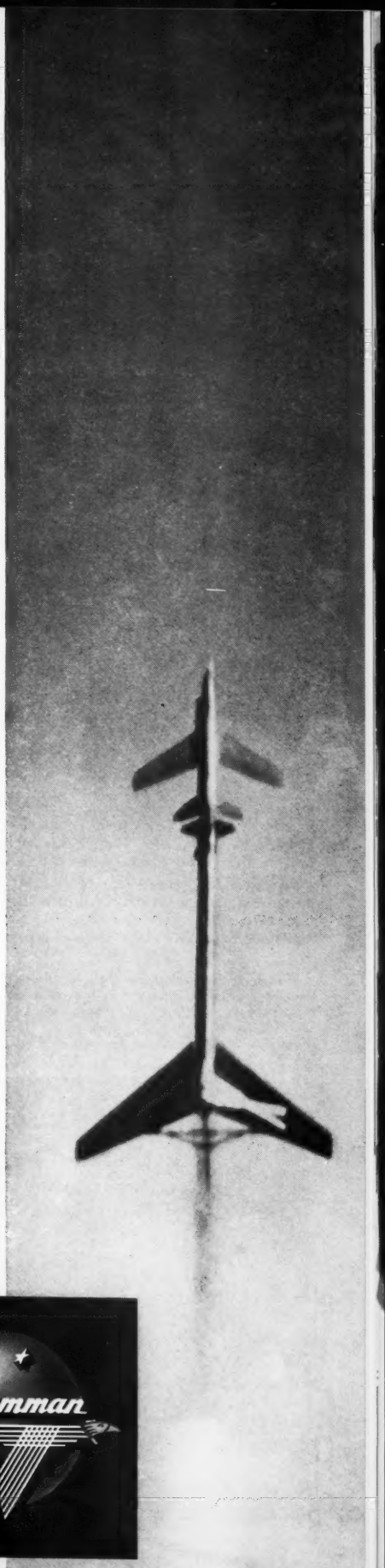
Designers and builders of supersonic Tiger, transonic Cougar, S2F sub-killer, Albatross amphibian, metal boats, and Aerobilt truck bodies



CORPORATE MEMBER NEWS

• **Air Associates, Inc. . . .** The Electronic Equipment Division, Orange, N.J., announces a new 1-kw. VHF-UHF amplifier for ground-to-aircraft communications. Model 23A amplifies 100 watts to more than 1,000 watts. . . . The Aircraft Products Division, Teterboro, N.J., is manufacturing an a.c. electromagnetic clutch-brake that operates without slip rings or rectifier. The M-6390 is designed for use with 400-cycle a.c. induction motors in a 115-volt, 3-phase standard aircraft system.

• **Aircraft Radio Corporation . . .** The new ARC CD-1 Course Director weighs less than 10 lbs. and operates on only 3.5 amp. at 14 volts d.c. or 2 amp. at 28 volts d.c. It provides headings for instrument approaches and en route tracking on omni- and visual-aural VHF ranges.

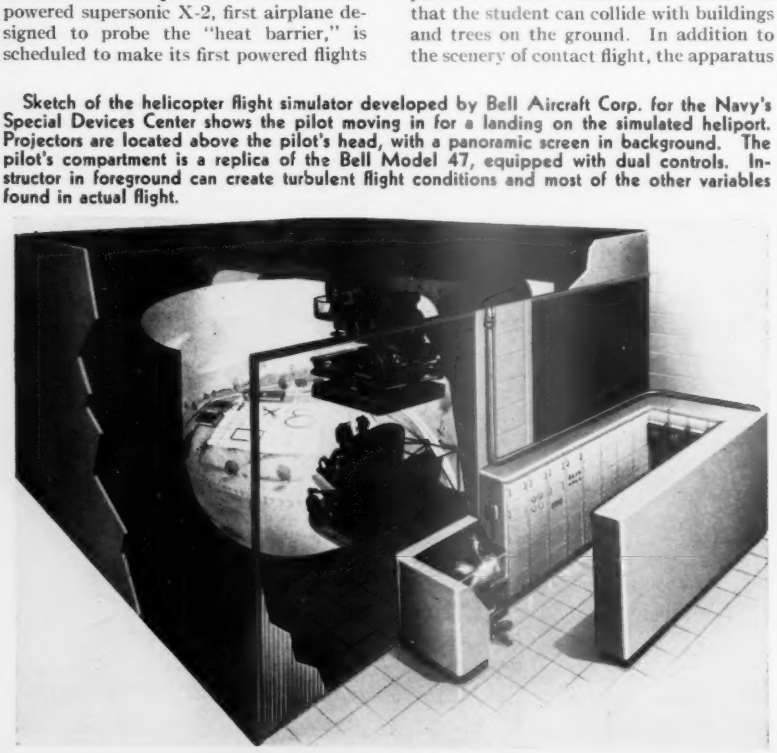
• **American Airlines, Inc. . . .** Nelson Lee Smith, former Chairman of the Federal Power Commission and the New Hampshire Public Service Commission, has been elected Vice-President—Economics.

• **American Bosch Arma Corporation . . .** V. Charles Schorlemmer has been named Administrative Vice-President. He is a former Vice-President and Secretary-Treasurer of Consolidated Vultee Aircraft Corporation.

• **Beech Aircraft Corporation . . .** An engineering office has been opened in Boulder, Colo., as an extension of the main engineering division in Wichita, Kan.

• **Bell Aircraft Corporation . . .** The rocket-powered supersonic X-2, first airplane designed to probe the "heat barrier," is scheduled to make its first powered flights this year at Edwards AFB. It is expected to surpass the record speed of 1,650 m.p.h. set by the Bell X-1A. The swept-wing X-2, which has passed a number of glide tests at Edwards, was built with stainless steel and K-monel replacing aluminum to a large extent in the wings and fuselage, because these metals are better able to withstand aerodynamic heating. The research plane will be powered by a Curtiss-Wright rocket engine. Carried aloft by a B-50 bomber, it will gain additional time in the air by having a flat skid landing gear instead of wheels. This allows more room for fuel. Highly tempered glass capable of withstanding almost 1,000°F. has been used for the windshield. To obtain data useful in designing high-speed aircraft, the wings and fuselage of the X-2 will be crammed with automatic recording instruments and radio telemeters during its assault on the heat barrier. . . . Under contract with the Special Devices Center of the Office of Naval Research, Bell has developed a helicopter flight simulator for use at Pensacola NAS, where it will provide the equivalent of 4 hours of primary flight instruction. The Model 2-FH-2 trainer has three main components: a projector, cockpit, and computer. The illusion of flight is obtained by projecting a small, brilliant light through a colored landscape built in miniature in a 6-ft. square plastic transparency over the pilot's head. Models of trees, houses, walls, and fences stand out vividly on a panoramic screen. The effect is so realistic that the student can collide with buildings and trees on the ground. In addition to the scenery of contact flight, the apparatus simulates control motions and pressures, instrument readings, fuselage vibration, engine and rotor noise, rough air and gusts, effects of gross weight changes, effects of c.g. location changes, engine failure, and the landing thump. . . . Bell is developing an all-metal blade as a possible replacement for the wood, metal, and fabric rotor used on the H-13 helicopter. Made of bonded aluminum-alloy sheet and extrusions, with a protective strip of stainless steel, the new blade has a 35.75-ft. rotor diameter, an 8° twist, and an 11-in. chord.

Sketch of the helicopter flight simulator developed by Bell Aircraft Corp. for the Navy's Special Devices Center shows the pilot moving in for a landing on the simulated heliport. Projectors are located above the pilot's head, with a panoramic screen in background. The pilot's compartment is a replica of the Bell Model 47, equipped with dual controls. Instructor in foreground can create turbulent flight conditions and most of the other variables found in actual flight.



• **Bendix Aviation Corporation . . .** A million-dollar facility is being constructed on a 46-acre site near Detroit for the Research Laboratories Division. The new building will provide 85,000 sq.ft. of floor space and will be fully air conditioned. . . . A 12,000-sq.ft. addition is under construction at the Pioneer-Central Division plant in Davenport, Iowa.

• **The Chase Manhattan Bank . . .** Chase Manhattan has joined four other large commercial banks in establishing the American Overseas Finance Corporation to provide private financing facilities to American manufacturers and exporters of productive capital goods, thereby enabling them to offer longer term credit to their customers abroad. A descriptive brochure may be obtained from the A.O.F.C., 30 Pine St., New York 5, N.Y.

• **The Cleveland Pneumatic Tool Company . . .** A sales and service office convenient to several aircraft plants has been opened at 3000 Hempstead Turnpike, Levittown, Long Island, N.Y.

• **Convair, A Division of General Dynamics Corporation . . . .** A separate department has been established to direct research and development on atomic-powered aircraft at Convair's Fort Worth plant. The new department is expected to enable Convair to discharge more effectively its increasing obligations to the Air Force in the field of nuclear aircraft development. . . . A company-sponsored research program to determine the ultrasonic effects of jet-engine noise and aerodynamic friction on various aircraft materials is under way in the engineering test laboratory at Convair-Fort Worth. Engineers and chemists are studying the effects of ultrasonics (20 kc. and up) on fuels, lubricants, hydraulic fluids, plastics, and adhesives, as well as possible changes in explosive limits of fuels. Information obtained from these tests will help the company design future aircraft to withstand any possible effects of intense ultrasound.

• **Douglas Aircraft Company, Inc. . . .** A downward ejection seat has been designed for the X-3 research airplane. If the pilot should be forced to abandon his plane at a high altitude, he will ride the seat down to 15,000 ft. in a free fall, then be separated from the seat and continue the descent with his parachute. While falling, the seat is stabilized in an upright position by two fins. Experiments to prevent tumbling were carried out in wind tunnels, on a rocket sled, and by dropping a seat from the bomb bay of a jet bomber. The X-3's complete oxygen system is attached to the seat and is ejected with the

Aircraft Heat Exchangers...

As performance requirements go up, Clifford's Wind Tunnel Laboratory assumes a major industry role.

The numerous heat exchangers illustrated on this page have one important thing in common. They all represent successful answers to heat transfer problems that hadn't been solved until Clifford's Wind Tunnel facilities were put to work.

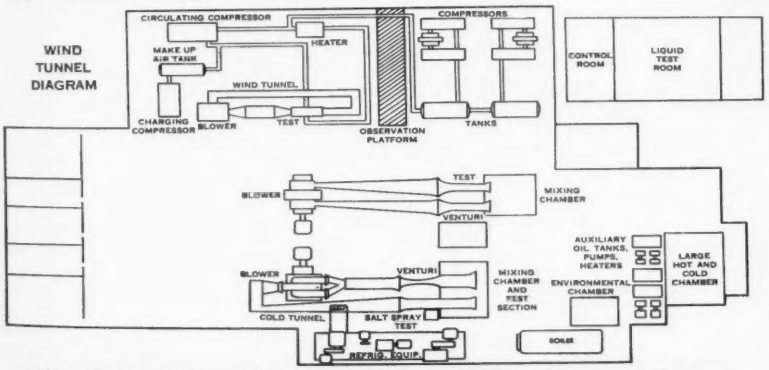
Each one of these heat exchangers represents a different problem — and some of them were highly unusual, involving designs featuring very high capacities within strict limits of space, weight and sometimes shape. In each case, Clifford designed and manufactured the thermal valves that control the oil flow, producing a complete "package" ready to mount for service.

Units have been developed for many different applications, including temperature control of engine lube oil, hydraulic system fluids, afterburner lubricant, cabin, cockpit, gun and camera compartments as well as wing and empennage anti-icing equipment. Recent work of interest includes special air type lube oil coolers for jets to meet "high altitude idling" conditions, oil coolers to meet the highly variable conditions encountered by helicopters in their changes of flight direction from vertical to horizontal. The problems of rocket flight, missiles and the temperature control of avionic equipment are currently receiving attention. The company is also deep into the unusual problems of heat exchange involving the handling of molten metals for atomic energy applications.

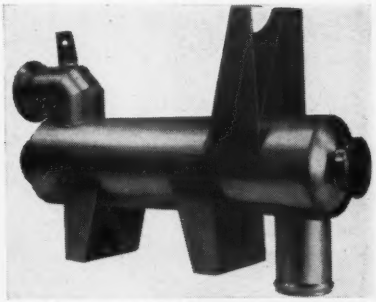
In all these areas, Clifford's unmatched facilities for development and design plus production capacity to provide heat exchangers in needed quantities is your finest assurance of securing the best solution to your problem.

A letter or phone call will put the world's most completely equipped technical facility of its kind to work on *your* problem. Clifford Manufacturing Company, 152 Grove Street, Waltham 54, Mass. *Division of Standard-Thomson Corporation.*

Telephone: WAltham 5-7310. Branch offices in New York, Detroit, Chicago and Los Angeles. 7.5.80

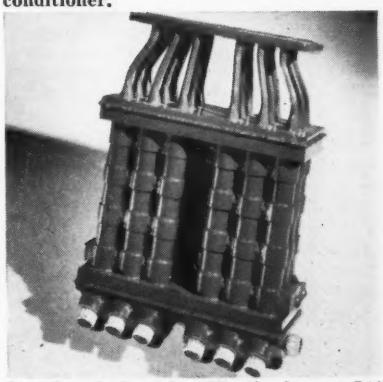


Clifford's Wind Tunnel facilities provide capabilities for accurately reproducing the conditions encountered by aircraft in actual service on any part of the globe and at altitudes from sea level to 80,000 feet.

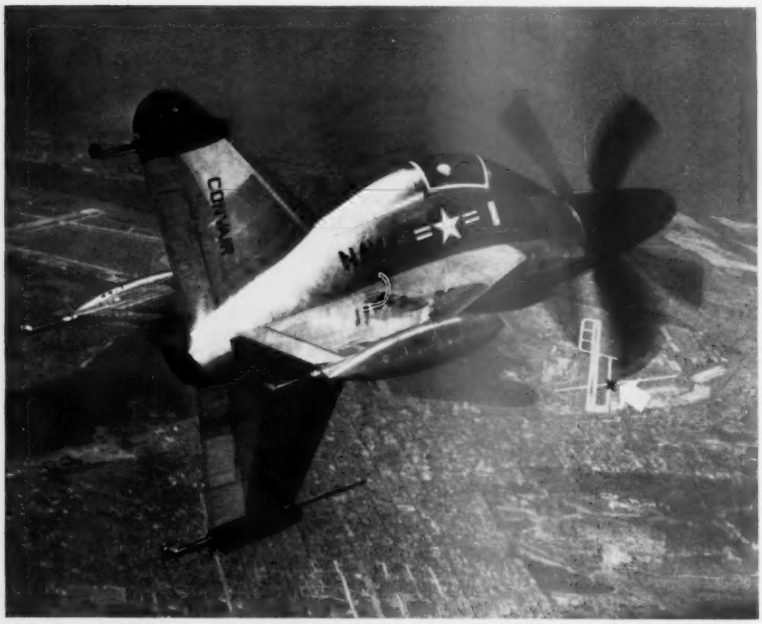


Stainless steel high temperature air-to-air heat exchanger. Clifford's ability to weld and braze stainless steel successfully, plus its unique test facilities gives the company unusual advantages in the new high temperature ranges of aircraft heat exchange applications.

How to put adequate heat transfer capacity into a restricted space in Republic's RF84F camera compartment to prevent camera port fogging was the problem solved by this Clifford air conditioner.



Developed for the Westinghouse J46 turbojet engine, this oil cooler was first to employ the vaporizing principle in lube oil cooling service. It provided greater heat rejection capacity per unit of fuel flow than ever previously attained.



The Convair XFY-1 flies over San Diego at 500 m.p.h. in a test flight. Arrow at right indicates the small area of the runway (only 50 ft. square) at Lindbergh Field which the VTO plane uses for take-off and landing. The turboprop plane was developed and built for the Navy, to take off vertically from a ship's deck. It lands tail-down on four castered wheels.

escaping pilot, thus eliminating the need for a bail-out bottle. The pilot's helmet, G-suit, and oxygen apparatus have been modified to withstand the wind blasts at supersonic speeds. Engineers say the force required to shoot an ejection seat up and over the X-3's tail at extremely high speeds would have been beyond human endurance, and an upward-opening canopy would have created too much drag for practical operation.

• **Eaton Manufacturing Company . . .** The Stamping Division has moved to a larger plant at 17877 St. Clair Ave., N.E., Cleveland, increasing its capacity by about 40 per cent. The company spent more than $3,000,000 in moving heavy machinery 38 blocks and installing new machines —including 10 presses—for stamping, plating, automatic polishing, welding, and tooling.

• **Electrol Incorporated . . .** Robert L. Firth has been elected Vice-President in charge of marketing. He was formerly Staff Manager of the Sales Promotion and Advertising Department of New York Air Brake Company.

• **Ethyl Corporation . . .** More than 4,000,000,000 lbs. of tetraethyl lead, the principal ingredient of Ethyl antiknock compound, have been manufactured since the gasoline additive was introduced 32 years ago. The company estimates that 520,000,000,000 gals. of motor and aviation gasoline have been improved with Ethyl fluid.

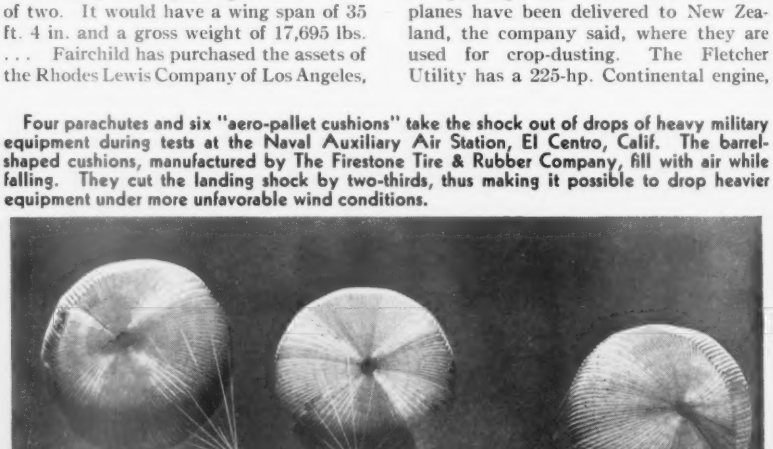
• **Fairchild Camera and Instrument Corporation . . .** Two new 70-mm. photofluorographic film viewers have been placed on the market by the Industrial Camera Division, Syosset, N.Y. Used in mass photoradiography, the viewers permit the reading of a large number of negatives over a long period of time with a minimum of eye fatigue. Magnification is approximately two diameters. One model is used for viewing roll film, the other for cut film.

• **Fairchild Engine and Airplane Corporation . . .** A light jet transport designed to cruise at 560 m.p.h. has been proposed to industrial fleet operators and military agencies by the Fairchild Aircraft Division. Powered by four Fairchild J44 jet engines, the low-wing executive transport would carry seven passengers and a crew of two. It would have a wing span of 35 ft. 4 in. and a gross weight of 17,695 lbs. . . . Fairchild has purchased the assets of the Rhodes Lewis Company of Los Angeles, a subsidiary of McCulloch Motors Corporation. Stratos Division of Fairchild has assumed direction of the Rhodes Lewis sales and engineering program and is continuing production in Los Angeles. Rhodes Lewis made high-pressure compressors, valves, ejectors, and related items. These products will be integrated with the output of Stratos Division, which specializes in pneumatic aircraft accessories.

• **The Firestone Tire & Rubber Company . . .** A barrel-shaped, collapsible rubber bag designed and manufactured by Firestone will greatly increase the striking power of paratroops. It absorbs the landing shock when a jeep, bulldozer, field gun, or other heavy piece of equipment is dropped by parachute. Four to 10 of the "aero-pallet cushions" are placed underneath a magnesium pallet carrying up to 25,000 lbs. of equipment. When the load is dropped from a cargo plane such as the C-130, a rush of air fills the cushions, then automatically closes diaphragms that keep them inflated. Upon hitting the ground, the air in the cushions bears the brunt of the shock. The suddenly compressed air forces out a rubber corklike plug, allowing the bag to collapse slowly, like an air-filled pillow. The cushions, which are made of nylon tire cord fabric covered with rubber and reinforced with strands of steel bead wire, can be reused about 20 times. Air Force tests have proved the air bags reduce the impact by two-thirds. A 1,000-lb. load hits the ground with a force of 12,000 lbs. instead of 35,000 lbs. Not only can heavier items be dropped, but rigging time is reduced and fewer parachutes are needed.

• **Fletcher Aviation Corporation . . .** The Fletcher FU-24 "Utility" has been certificated by the CAA for agricultural, cargo, and passenger use. More than 50 of the planes have been delivered to New Zealand, the company said, where they are used for crop-dusting. The Fletcher Utility has a 225-hp. Continental engine,

Four parachutes and six "aero-pallet cushions" take the shock out of drops of heavy military equipment during tests at the Naval Auxiliary Air Station, El Centro, Calif. The barrel-shaped cushions, manufactured by The Firestone Tire & Rubber Company, fill with air while falling. They cut the landing shock by two-thirds, thus making it possible to drop heavier equipment under more unfavorable wind conditions.

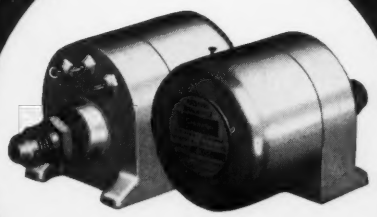


42-ft. wing span, and tricycle landing gear. It has a hopper that can hold 27 cu.ft. of fertilizer or can be converted into a 50-cu.ft. carryall. As a personnel carrier it takes six passengers. The pilot is protected by an extra-strong cockpit. The plane has an all-movable elevator system for ease of control at low speeds.

• **General Electric Company** . . . A new lightweight computing gunsight has been developed for supersonic jet fighters. G-E says the K-19 is considerably lighter than previous models but maintains a high degree of reliability and accuracy. Designed for ease of maintenance and reduction of weight and complexity, the new sight can be used with all weapons carried by a day fighter for both air-to-air and air-to-ground firing. . . . The G-E Instrument Department has developed a tiny motor no larger than a man's thumb for a wide variety of aircraft applications. The 26-volt motor was originally designed for use in the gyro component of the MA-1 compass-controlled directional gyro-compass system, but engineers believe it can be adapted to many other uses by designers of aircraft instruments and servosystems. . . . G-E has published a summary of its guided-missile programs during the past decade in the form of a two-page bulletin. This may be obtained from the Special Defense Projects Department in Schenectady, N.Y., a newly formed department engaged in the engineering and production of large, highly complex defense systems. It acts as a focal point for the company's engineering and manufacturing resources on special defense systems projects requiring the close, coordinated efforts of many G-E organizations. . . . Six J47-GE-23 jet engines on a Boeing B-47B bomber of the Strategic Air Command at Pinecastle AFB, Fla., have set a new mark as the first complete group of jet power plants on a multiengined plane to pass 1,000 flying hours without major overhaul, the company announced. At an average air speed of 600 m.p.h., the distance flown by this plane during the 1,000 hours was equivalent to flying 24 times around the world. The six J47 engines were installed in November, 1952. . . . Despite desert sand and winds, the 413th Day Fighter Group at George AFB, Calif., has flown its North American F-86H's an aggregate of 5,000 hours without a single engine being damaged by foreign objects, G-E reports. The planes are powered with J73 turbojets, which operate without air inlet screens.

• **G. M. Giannini & Co., Inc.** . . . The Datex Division, which manufactures digital data-recording equipment, has moved to 1307 South Myrtle Ave., Monrovia, Calif. . . . A new air-stream type of vane transducer, Model 25116, has the unique ability to "filter out" nonsignificant, localized high-frequency air-stream fluctuations. This instrument for measuring angle of attack provides optimum performance at altitudes up to 60,000 ft. and at speeds from Mach 0.2 to 2.0.

• **The Goodyear Tire & Rubber Company, Inc.** . . . Goodyear Aircraft Corporation has opened an office in the Ring Building, Washington, D.C., to facilitate its dealings with Government defense departments.



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• **Lear, Incorporated . . .** Lear-Romec Division announces the Model RG-6100E-1 electric-motor-driven hydraulic oil pump. This 1/4-hp. line-mounted lubricant pump feeds oil to the hydromechanical clutch in helicopter transmissions.

• **The Liquidometer Corporation . . .** The new Model 216 Remote Reading Tank Contents Indicator is well suited for airport fuel storage tanks, either buried or above ground, where remote indication of fuel quantity is required. The dial-type indicator, which may be located as far as 250 ft. from the float in the tank, is designed for use where panel space is limited. It may be mounted horizontally or vertically.

• **Lockheed Aircraft Corporation . . .** An "aerial delivery system" for the C-130 Hercules has been designed by engineers of the Georgia Division to permit parachute delivery of heavier and bulkier military weapons, vehicles, and equipment than have ever been dropped before. The Lockheed system utilizes two aluminum-alloy platforms, 9 ft. by 24 ft. and 9 ft. by 15 ft., which have a gross capacity of 25,000 lbs. and 15,000 lbs., respectively. Cargo up to a gross weight of 20 tons is loaded and fastened to these platforms, which run into the plane on roller conveyors. The pilot, while the airplane is in flight, can release the platforms by pushing a button in the cockpit. The button releases an extraction parachute, which disconnects one platform from the plane and quickly drags the loaded platform out the rear door. After the cargo-carrying pallet clears the airplane, an automatic mechanism opens several large 'chutes. The second platform follows the first in a matter of seconds. A shock-absorbing device developed by Lockheed and Firestone engineers cushions the ground impact. The platforms, parachutes, and shock absorbers are reusable. Air-drop delivery is expected to become more widespread when the first group of C-130 transports goes into operation with the Eighteenth Air Force next year.

• **Marquardt Aircraft Company and Reaction Motors, Inc. . . .** With Olin Mathieson Chemical Corporation, which has a substantial interest in these companies, Marquardt and Reaction Motors are engaged in a joint program of applied research to advance supersonic aircraft and missile propulsion. Linking mechanical experience in the development of supersonic engines with chemical experience in the manufacture of special fuels, the research and development program embraces the fields of advanced rocket and ram-jet engine design, improved rocket and ram-jet engine propellants, and special mechanical and chemical engineering processes. It is directed toward advancing basic propulsion science and providing improved methods for the production of rocket and ram-jet engines, their propellants, and related devices.

• **McDonnell Aircraft Corporation . . .** A missile-carrying version of the Demon, the F3H-2M, is in production for the Navy, and another Navy jet fighter, the F4H-1, is under development. . . . The Missile Engineering Division has developed an automatic drift computer for the F-101 Voodoo which enables the pilot to navigate

over long distances without obtaining information from the ground regarding wind direction and wind velocity. The computer operates in conjunction with the AN/ASN-6 ground position indicator, which instantaneously presents the airplane's latitude and longitude to the pilot by means of an indicator on the instrument panel. Thus it is possible for the pilot to navigate without seeing the ground or obtaining radio fixes along the way.

• **The Parker Appliance Company . . .** With successful formulation of the new synthetic rubber compound No. 47-671, Parker announces that aircraft hydraulic service O-rings are now available for the operating temperature range of −65° to +275°F. The new compound was developed to meet unusually rigid functional and physical requirements such as those in Government specification MIL-P-18017.

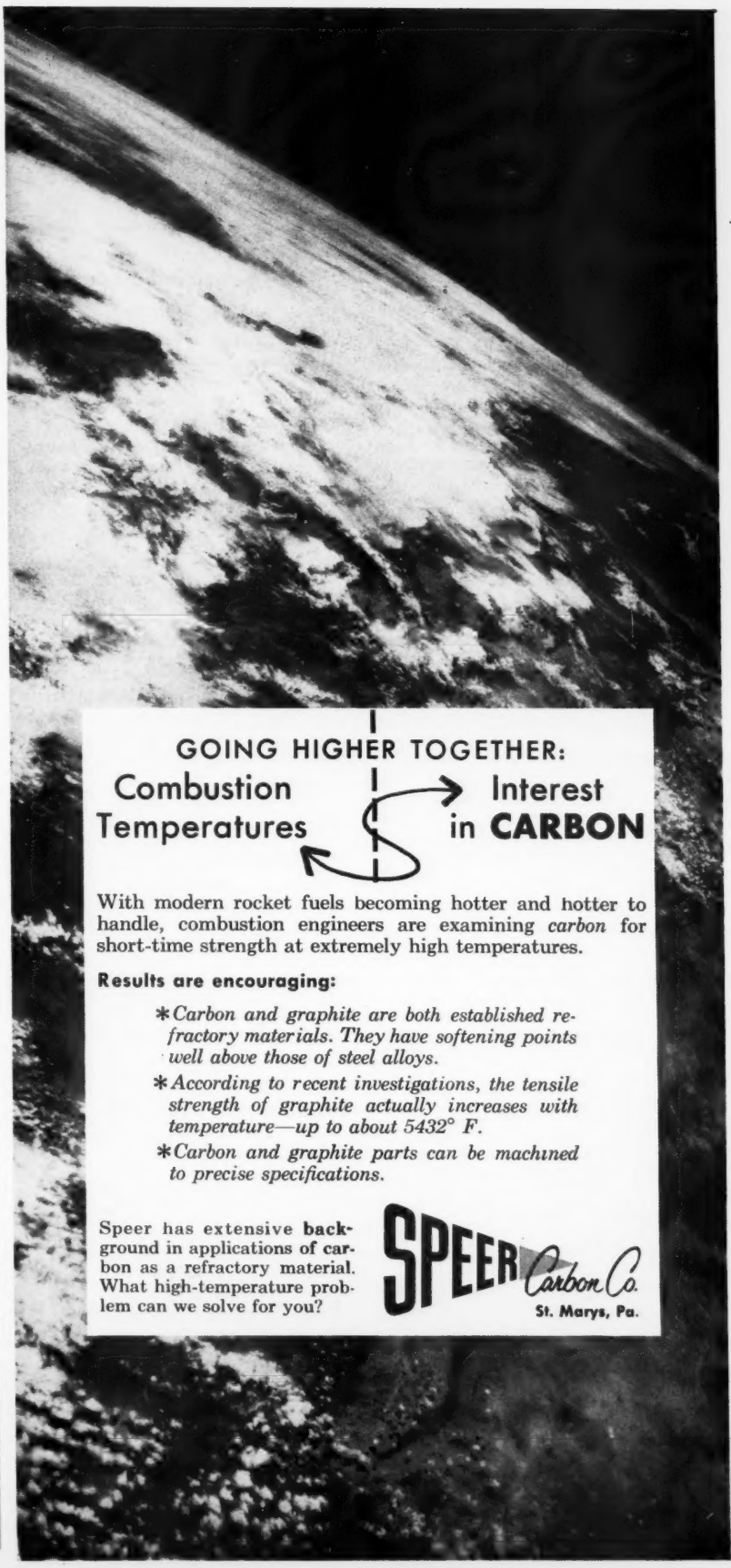
• **Piasecki Helicopter Corporation . . .** A branch engineering office has been opened in the Stoney Creek Business Center on Baltimore Pike, Springfield, Pa. About 120 engineers are employed there.

• **Radioplane Company . . .** A 25,000-sq.ft. pilot plant in El Paso, Tex., to be completed in January, will employ about 150 persons in engineering, production, repair, and modification work on drones and missiles. Radioplane's parent company, Northrop Aircraft, Inc., has acquired a 640-acre tract nearby. El Paso was chosen as a plant location because of its proximity to Holloman AFB, White Sands Proving Grounds, Fort Bliss, and other test centers for guided missiles and pilotless aircraft.

• **J. B. Rea Company, Inc. . . .** The Robey Rotor Company of Culver City, Calif., manufacturers of gyroscopes, blowers, and miniature motors for aircraft and guided missiles, has been acquired by the Rea Company. A new subsidiary is the J. L. A. McLaughlin Corporation of La Jolla, Calif., a research and manufacturing firm in the long-range communications field.

• **Republic Aviation Corporation . . .** The XF-84H experimental turboprop fighter has made its first flight successfully at Edwards AFB, the Air Force announced. Said to be the fastest single-engined propeller-driven plane ever built, it was designed to test the feasibility of using a supersonic propeller with a gas turbine to economize on fuel, thus gaining longer range than a jet fighter can attain. Because of its speed, long range, and ability to carry heavy armament loads and still take off from short runways, the XF-84H is said to meet the requirements for a USAF low-level fighter-bomber or a Navy carrier-based dive bomber. It is powered by an Allison XT-40 engine. An automatic propeller governor maintains a constant engine r.p.m.; speed changes in flight are controlled by automatic pitch change of the propeller blades. Propeller pitch can be reversed to brake the landing run. The XF-84H is believed to be the first turboprop plane designed for afterburner augmentation of propeller power.

• **Ryan Aeronautical Company . . .** Believed to be the first test cell capable of testing jet engines and afterburners in a vertical position, simulating conditions in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St. Marys, Pa.

a VTO aircraft, a $175,000 facility has been constructed at the San Diego plant to handle turbojets in either vertical or horizontal attitude. The new test cell also will be used in metallurgical research on blades and other high-temperature components of power plants.

• **Solar Aircraft Company . . .** An experimental 300-kw., 60-cycle generating set, employing the constant-speed version of Solar's 500-hp. Jupiter gas-turbine engine, is being constructed for the Navy's Bureau of Ships. It will be able to function automatically, within 10 sec. after the need arises. The Navy intends to study the practicability of gas-turbine-driven generator sets for both emergency and regular use aboard ships. A Jupiter engine is now under evaluation as the prime mover in a 400-cycle emergency generator set installed experimentally in the destroyer U.S.S. "Timmerman."

• **Trans World Airlines, Inc. . . .** A maintenance hangar 125 by 275 ft., large enough to house two Super G Constellations, is being constructed for T.W.A. at Philadelphia International Airport. Following the new concept of cantilever design, the hangar roof and curtain walls will be supported entirely by overhead bridge-type cables 30 ft. apart. The plans provide for a future extension which would double the width of the hangar, creating an open floor space 125 by 540 ft. with no interferring supports. Storage rooms, offices, workshops, and other auxiliaries will be located in two large "lean-to's"—something new in hangar construction. The structure will cost $1,225,927.

• **Westinghouse Electric Corporation . . .** A new direct-drive explosion-proof fractional horsepower a.c. motor, introduced by the Small Motor Division for aircraft applications, is equipped with a self-energized d.c. electromagnetic brake. When current to the motor is interrupted, this brake can decelerate the rotating motor from 11,300 r.p.m. to rest in less than 1/5 sec. The motor is available in ratings from 1/30 to 1/4 hp. and for speeds of 5,600, 7,500, or 11,300 r.p.m. It operates on a 400-cycle, 200-volt, 3-phase system.

IAS SECTIONS

Baltimore Section

The following officers have been elected for 1955–1956: Chairman, Ralph H. Draut; Vice-Chairman, Raymond D. Blakeslee; Secretary, Ray C. Robley, Jr.; Treasurer, Charles A. Speas; Area Councilor, Albert J. Kullas.

Members of the Advisory Board are George F. Towner, Herman C. Wieben, Jr., Paul A. Piper, Richard W. Sanford, Francis H. Clauser, Edward G. Uhl, Herman Pusin, and Lt. Col. H. C. Teubner, USAF.

RAY C. ROBLEY, JR., *Secretary*

Hampton Roads Section

The final meeting of the season was held June 29 in the NACA Activities Building at Langley Aeronautical Laboratory. Chairman Emanuel Boxer introduced the speaker, John Duberg, to approximately 60 members and guests interested in "High Temperature Structural Research at the NACA."

Duberg is head of the Structures Research Division of Langley Aeronautical Laboratory and well known to most of our members. He is one of the pioneers in the field of elevated temperature research and is responsible for the direction of NACA research in this field.

Consideration of the temperatures to be expected because of high-speed aerodynamic heating and the associated structural effects leads to a subdivision into two broad structural problems, he said—those associated with uniform temperature distributions and those associated with nonuniform temperature distributions.

For uniform temperature distributions, Duberg presented results for the predictions of the strength of built-up structural elements, selection of the most efficient materials at high temperatures, and prediction of creep lifetime of box beams and creep buckling of columns.

For nonuniform temperature distributions, he presented experimental results of box beams subjected to simultaneous loading and rapid heating, which showed that large increases in deformation under constant load and serious loss of stiffness in solid and shell structures resulted from thermal stresses produced during the transient phase of heating.

A motion picture showed the flutter of a wing in supersonic airflow with aerodynamic heating. The wing section exhibited no flutter in similar tests which did not involve heating, thus demonstrating an effect of the loss of stiffness due to heating.

WILLIAM D. MCCAULEY
Past Recording Secretary

Piasecki Helicopter Corp. has announced it will build a commercial version of the H-21 twin-rotor helicopter next year for air-line and industrial use. Called the PH-42, the civil version will carry 19 passengers and cruise at 98 m.p.h. Artist's sketch shows convertible cabin arrangement for both passengers and cargo, with additional space for mail and passengers' baggage in a detachable "helipack" beneath cabin.

Los Angeles Section

On July 28, a specialist meeting sponsored jointly by the Los Angeles Section and the Historical Branch of the Los Angeles Section featured a talk by Hidemasa Kimura, Professor of Aeronautical Engineering, Nihon University, Tokyo, Japan. The lecture, entitled "Japanese Aircraft Design—World War II and Today," attracted an audience of 100 Section members, Historical Associates, and guests.

The speaker reviewed the history of the Japanese aircraft industry prior to World War II. He showed how developments in the industry led to the design philosophy found in the aircraft built and flown by the Japanese during the war. This philosophy was characterized by aerodynamic refinements, light but complicated structures, poor

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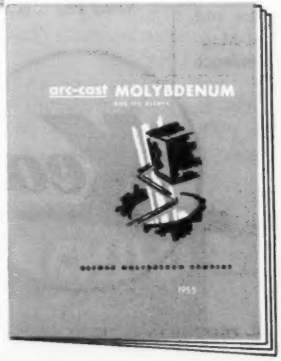

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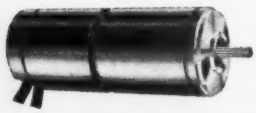

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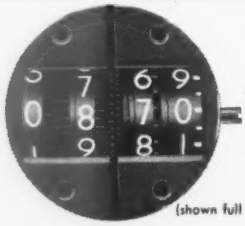

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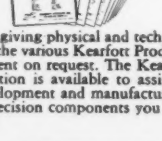

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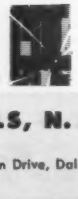

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equipment, light armament, and no armor. He then discussed the ability of the Japanese as aircraft designers, impressing the audience with the fact that the Japanese possess the originality and ability to design and build quality aircraft. However, he commented further, the aircraft industry in Japan was about 30 years behind in technical capability.

In conclusion, Kimura described the rebirth of the Japanese aircraft industry now taking place under the sponsorship of the Self-Defense Force. He noted that aircraft presently scheduled for production in Japan include jet trainers and liaison aircraft.

RICHARD BOYLES, JR.
Specialist Meetings Committee

▶ The speaker at a specialist meeting held on July 12 was Ron Manley, Director, Systems Engineering Institute, Los Angeles. The lecture, which was attended by 56 members and guests, was entitled "Future Developments in Systems Engineering and Operations Research."

Mr. Manley explained the expressions "systems engineering" and "operations research" by showing how they are actually brought into play in many events in everyday life—for example, the purchase of an automobile. In discussing possible future developments in these fields, he predicted college courses consisting of a single 4-year problem whose systematic solution would determine the student's course of study. This would give each course more meaning and hence stimulate better understanding.

HAROLD R. SWEET
Specialist Meetings Committee

▶ At a specialist meeting held on July 7, I. Irving Pinkel, Associate Chief of the Physics Division at the NACA's Lewis Flight Propulsion Laboratory, spoke on "NACA Crash-Fire Research." Ninety members and guests of the Section attended.

Mr. Pinkel discussed the results of more than 5 years of research investigating the causes, manner of development, and means of prevention of fires that occur during airplane crashes. Some interesting results of the test program were as follows:

(1) Water cooling of critical hot spots in the engine when a crash occurred removed the engine as a source of fuel ignition.

(2) Temperatures in and around the airplane were not above human tolerance until approximately 110 sec. of burning time had elapsed.

(3) Rearward facing seats on flexible mounts increased the chances of a passenger's being physically capable of taking advantage of this time to escape from the aircraft.

EDWARD F. VERSAW
Specialist Meetings Committee

Niagara Frontier Section

The following new officers have been elected for 1955–1956 and will be installed at the October meeting: Chairman, Clifford Muzzey; Vice-Chairman, Herbert Asbury; Secretary, David Whitcomb; Treasurer, James O'Malley.

Members of the Advisory Board are: William Champney, Lester Fero, Robert Kluge, Alexander Krivetsky, Everett Welmers, and George Melrose. Robert Goldin is Representative to the Area Councilor Nominating Committee.

GEORGE B. MELROSE, JR., *Chairman*

Philadelphia Section

New officers are as follows: Chairman, Louis P. Clark; Vice-Chairman, Earle Stewart; Secretary, Harold Peterson; and Treasurer, Harold Kaufman.

The Advisory Board for 1955–1956 consists of Courtland Perkins, Samuel Berkowitz, Dale Hamilton, Philip Krause, Alfred A. Little, Alfred L. Wolf, John S. Kean, Adolph Herzog, Robert B. Cotton, and Emily Rogers Gibbs.

St. Louis Section

These officers have been elected for 1955–1956: Chairman, Allen H. Madrick; Vice-Chairman, Charles J. Kippenhan; Corresponding Secretary, John F. Yardley; Recording Secretary, Frederick H. Roever; Treasurer, Chester V. Braun; Advisory Board, Robert J. Baldwin and Fredrich L. V. Doblhoff.

L. A. SMITH, *Past Secretary*

Tullahoma Section

The August 1 meeting was opened by President Jim Sivells. After a short business session, Program Chairman W. C. Wimbrow introduced Chester Linsky, who was on summer leave from the faculty of Pennsylvania State University. During the summer he served as a Consultant in Industrial Engineering at the Arnold Engineering Development Center.

The speaker's subject was "Automation." His talk, illustrated with slides, presented the history of the development of automation and summarized the many aspects of automation, using the metalworking industry as an example.

Linsky pointed out that all industry today, in the face of increased costs, is approaching automation by degrees. He stated that the essential starting point in achieving automation is product design, wherein the design may have to be esthetically compromised in order to obtain a product suitable for an automation process. The limits of automation, however, lie not in the product but in the processes involved. Dimensional

OPERATIONS ENGINEERS

Concurrent with the establishment of a Military Relations Department at the Fairchild Aircraft Division, an Operations Engineering organization has been established. The purpose of this new group is to provide technical information for use by Fairchild Military Relations representatives, as well as by personnel in Fairchild's engineering departments. This new group will conduct studies on specific Fairchild airplanes, as well as systems studies relating to possible future Fairchild developments.

The scope of this organization is such that additional engineers are required in the following fields:

Aircraft Utilization
Airborne Electronics
Climatology
Economics
Military Operations
Operations Research
Propulsion

The opportunities and salaries associated with the new positions are in keeping with the responsibilities of this work. Employee benefits in the form of group insurance, individual and family coverage for hospitalization, retirement plan, sick leave, etc., are also provided.

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accuracy and quality control ultimately limit the degree of automation attainable.

Ultimately the goal of automation is the complete feedback control system capable of returning the product to its desired quality, thus minimizing costly shutdowns.

After the talk, a movie entitled *Operation Tinker Toy* was shown to illustrate several automation processes.

ERNEST A. SANLORENZO, *Secretary*

MEMBERS ELECTED

The following applicants for membership or applicants for change of previous grades have been admitted since the publication of the list in the last issue of the Review.

Elected to Associate Fellow Grade

Douglas, George F., B.S., Asst. Chief Engr., Northrop Aircraft, Inc.

Farver, Lyle L., Sr. Devel. Engr., McDonnell Aircraft Corp.

Gloeckler, Frederick M., B. of Ae.E., Tech. Dir., Analytical & Computer Dept., NADC (Pa.).

Polhamus, Edward C., B.S.M.E., Aero Research Scientist—Stability & Control, Langley Lab., NACA.

Transferred to Associate Fellow Grade

Holmes, William C., Jr., M.A., Chief, Power Plant Engrg. Dept., Northrop Aircraft, Inc. (Hawthorne).

Lukasiewicz, Julius, B.Sc., Head, High Speed Aerodynamics Lab., Aerodynamics Sect., Mech. Engrg. Div., National Research Council (Ottawa).

Schwarzbach, Jerome M., M.S. in M.E., Special Asst. to Chief Engr., Flight Test Div., NATC (Patuxent River).

Elected to MEMBER Grade

Barr, C. James, Ph.D., Group Head, Rocket Propellant Sect., Explosives Div., Olin Mathieson Chemical Corp.

Barr, Louis, B.S. in Ae.E., Flight Engr., Trans World Airlines, Inc. (Kansas City).

Blake, T. Gaynor, B.A., Mgr., R&D Dept., Explosives Div., Olin Mathieson Chemical Corp.

Boulton, Douglas, B.Sc., Dynamics Engr., Canadair, Ltd.

Bozajian, John M., M.S. in M.E., Head, Analysis Group, Structs. & Materials Sect., Guided Missile Labs., Hughes Aircraft Co.

Cheney, Gordon H., Group Engr., Supervisor—Wind Tunnel Instrumentation, Boeing Airplane Co. (Seattle).

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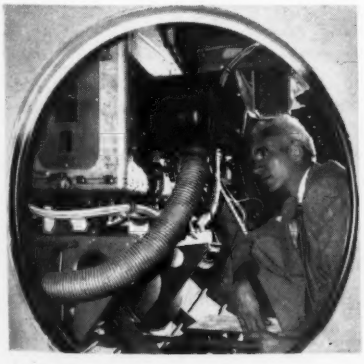

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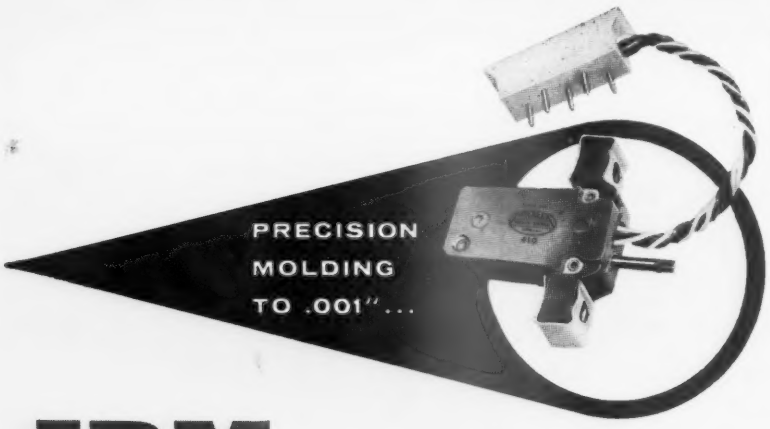

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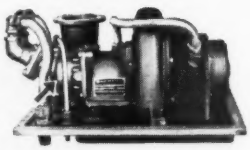

Fuel Transfer Pump built by Nash Engineering Co. for Boeing KC-97 Tanker. Powered by Vickers "Instant Response"* Hydraulic Motor.

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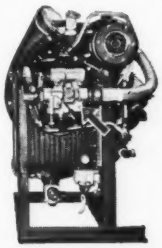

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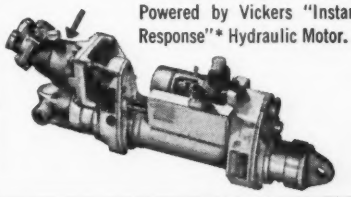
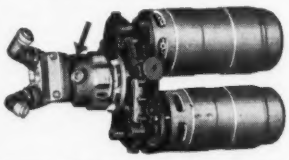


ALTERNATOR GENERATOR DRIVE



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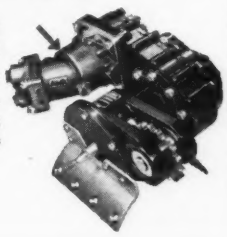

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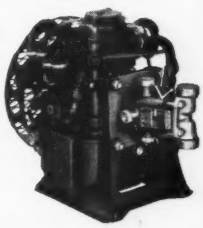

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The Asymptotic Boundary Layer on a Circular Cylinder in Axial Incompressible Flow. K. Stewartson. *Quart. Appl. Math.*, July, 1955, pp. 113–122.

Boundary-Layer Growth. E. J. Watson. *Proc. Royal Soc. (London), Ser. A*, July 19, 1955, pp. 104–116. Extension of the Blasius theory of the growth in a viscous fluid at a cylinder started from rest.

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Méthode de Calcul de la Couche Limite Tridimensionnelle; Application à un Corps Fuselé Incliné Sur le Vent. E.-A. Eichelbrenner and A. Oudart. *France, ONERA Pub. 76*, 1955. 49 pp. In French. Method based on the use of equipotential and wall streamlines of the perfect non-rotational flow to determine the three-dimensional boundary layer applied to an ellipsoid spindle-shaped body of revolution with the axis inclined ten degrees into the wind.

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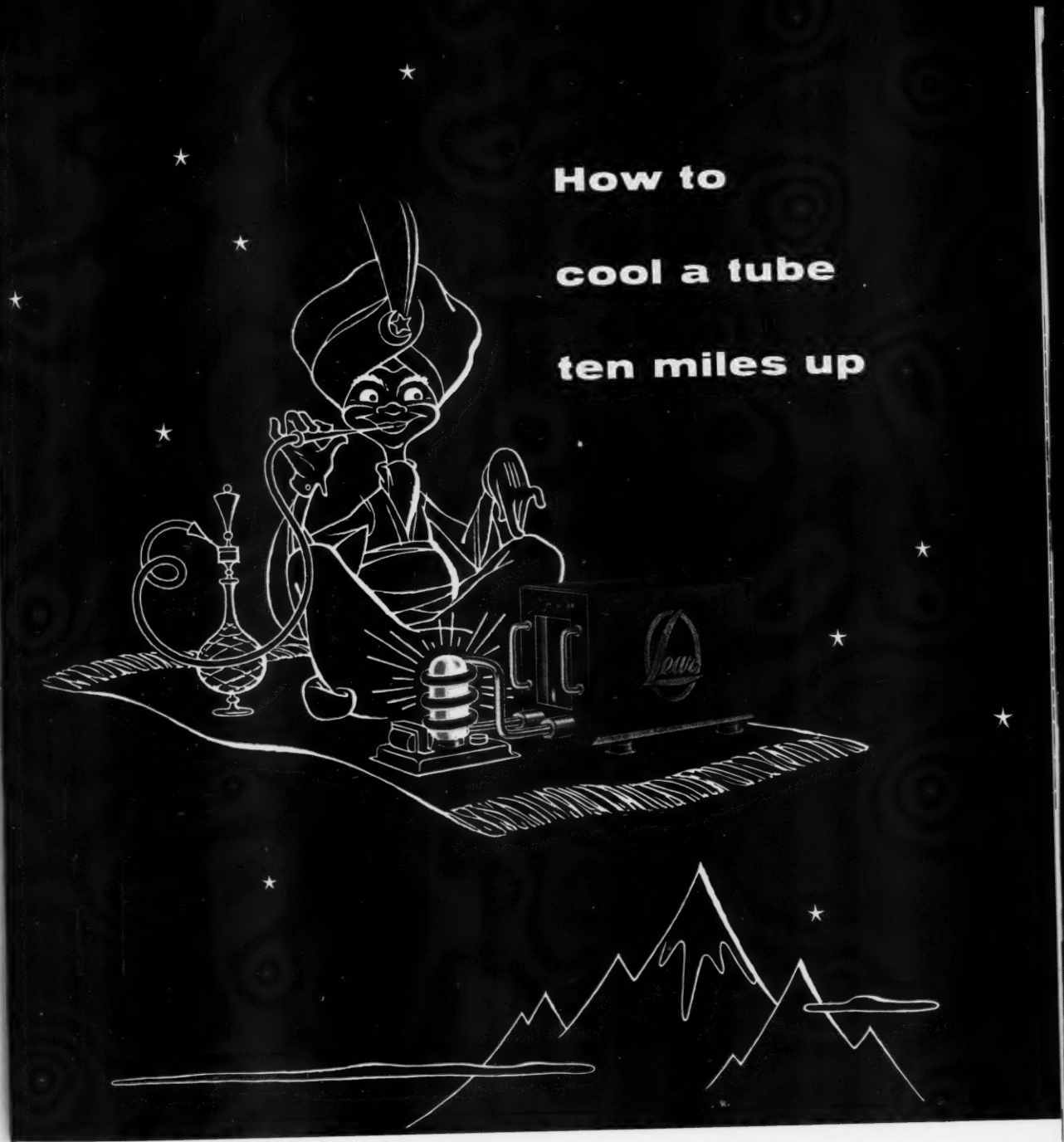

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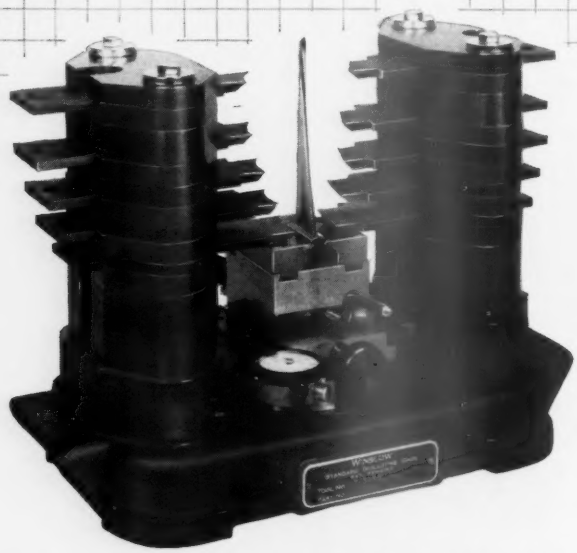

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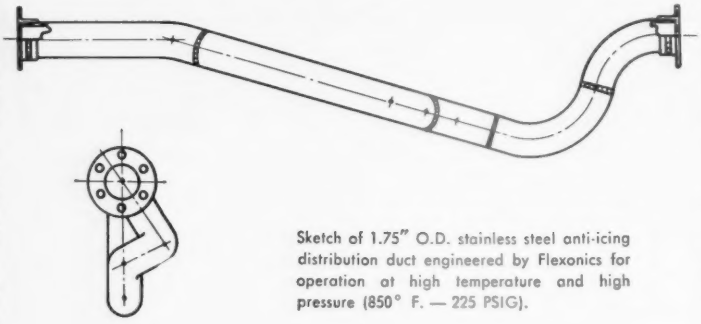

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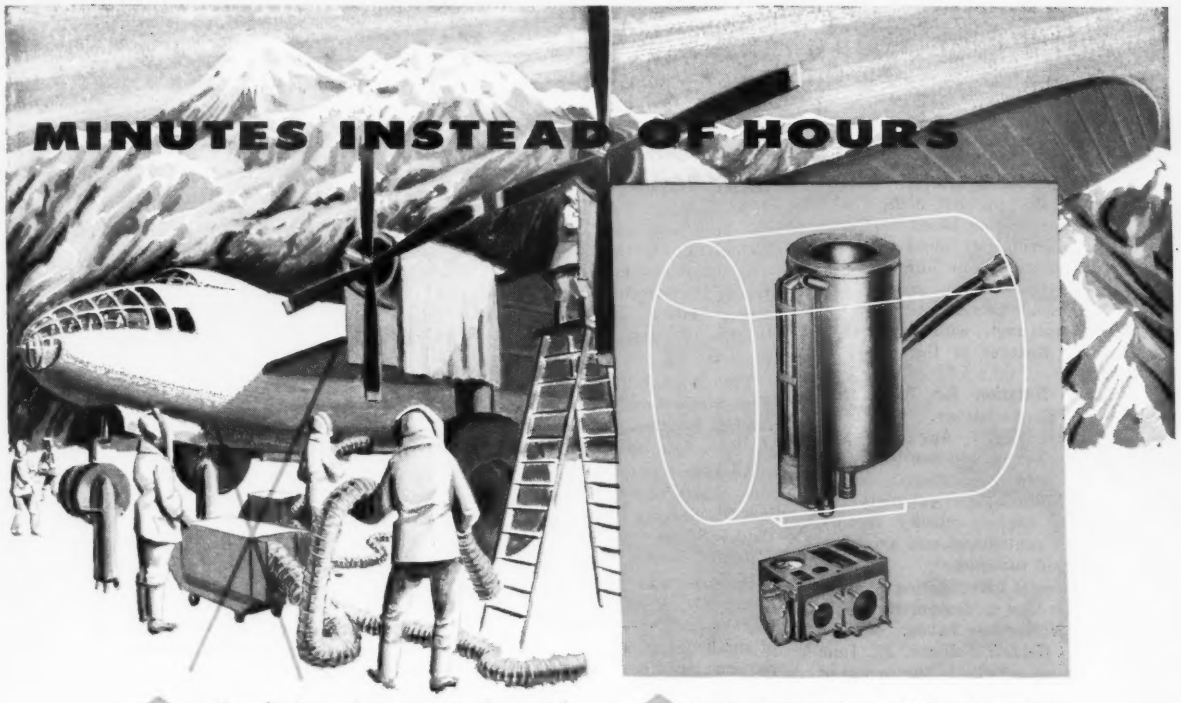

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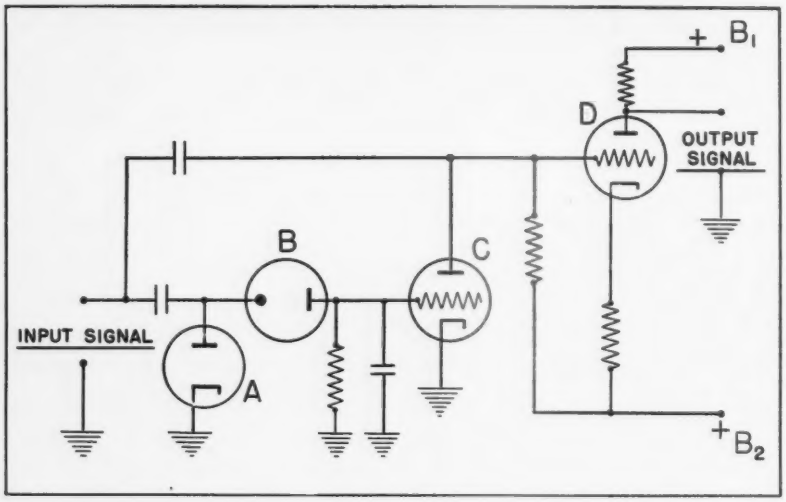

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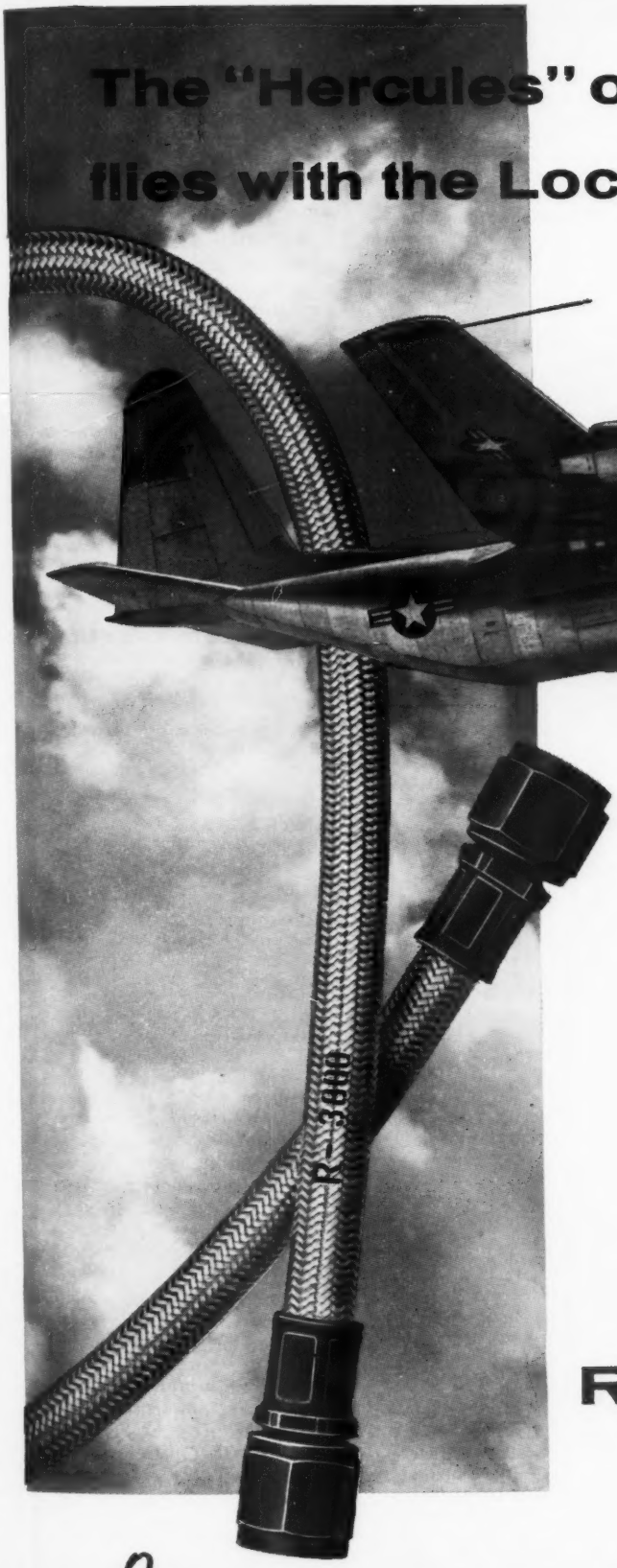

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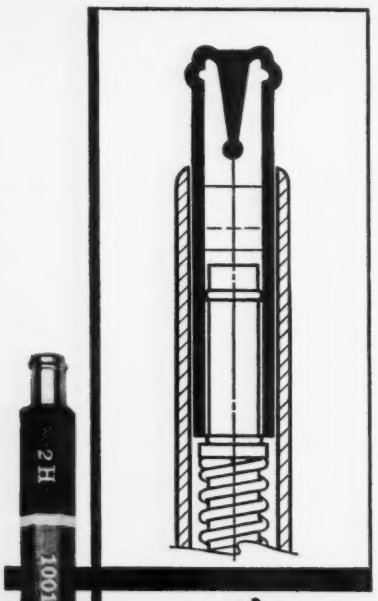

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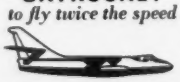

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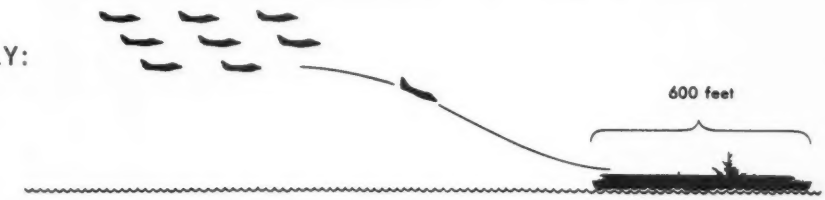

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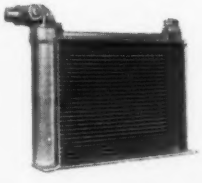

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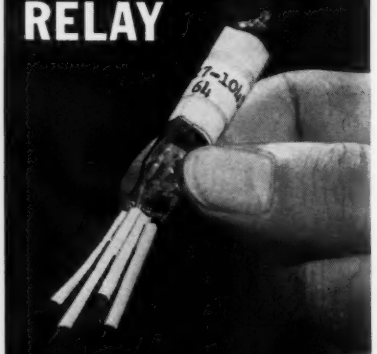

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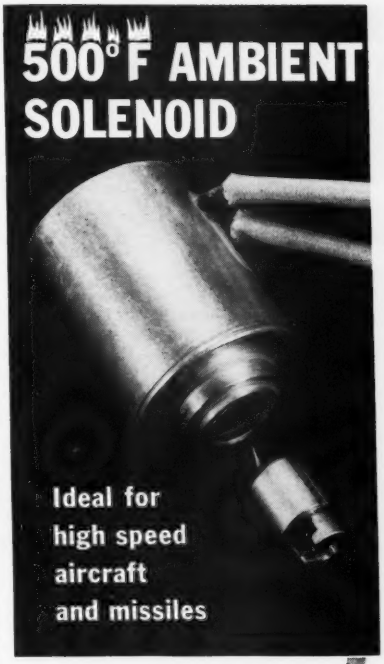

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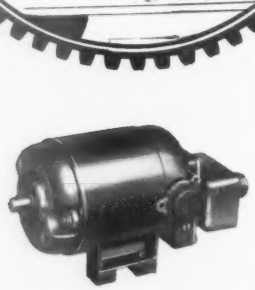

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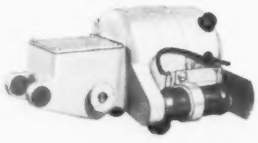

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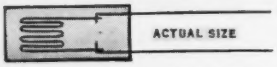

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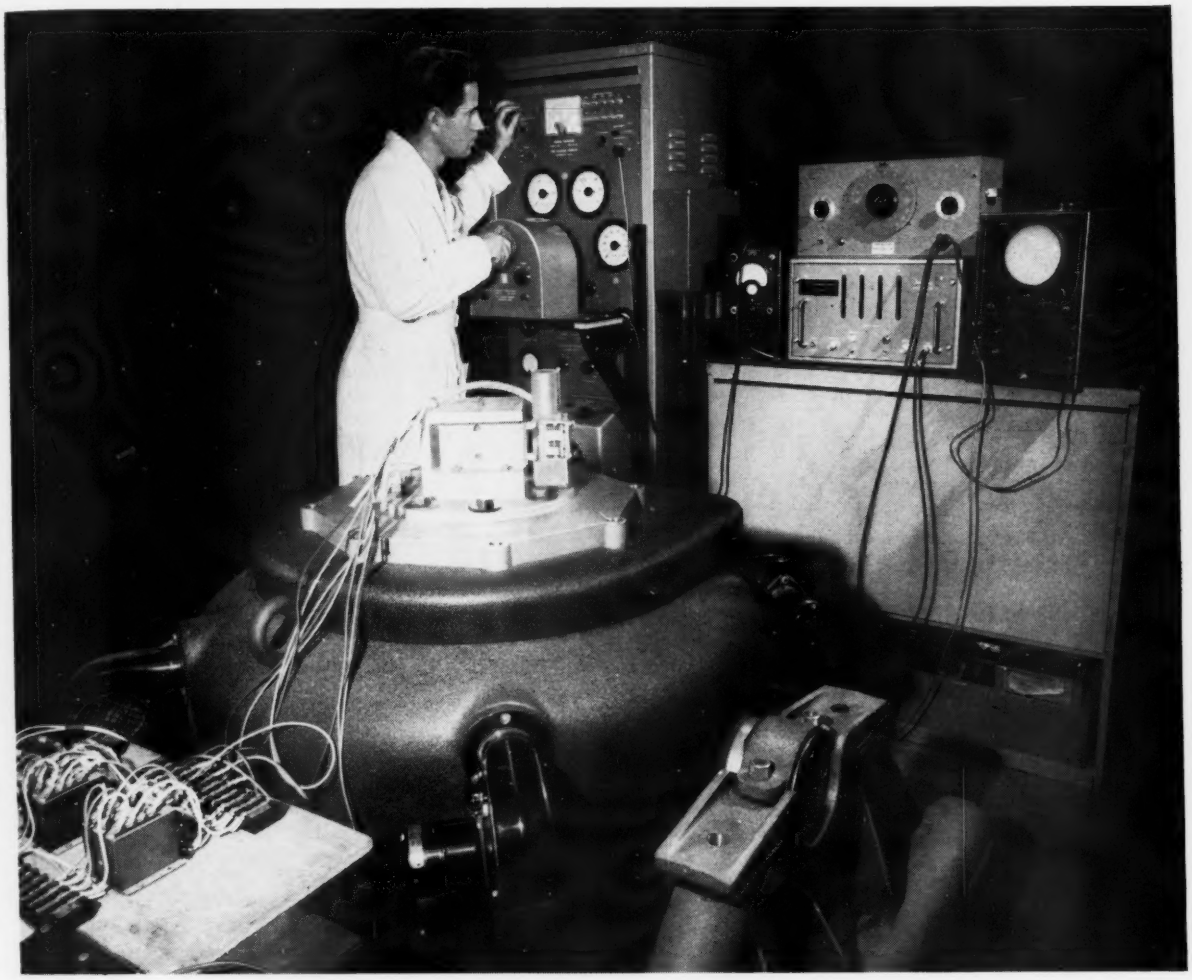

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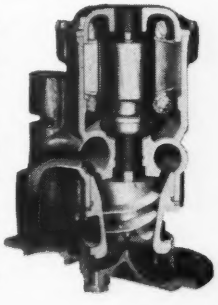

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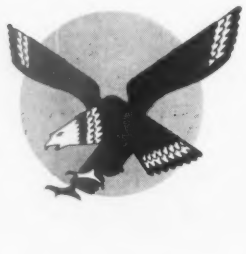

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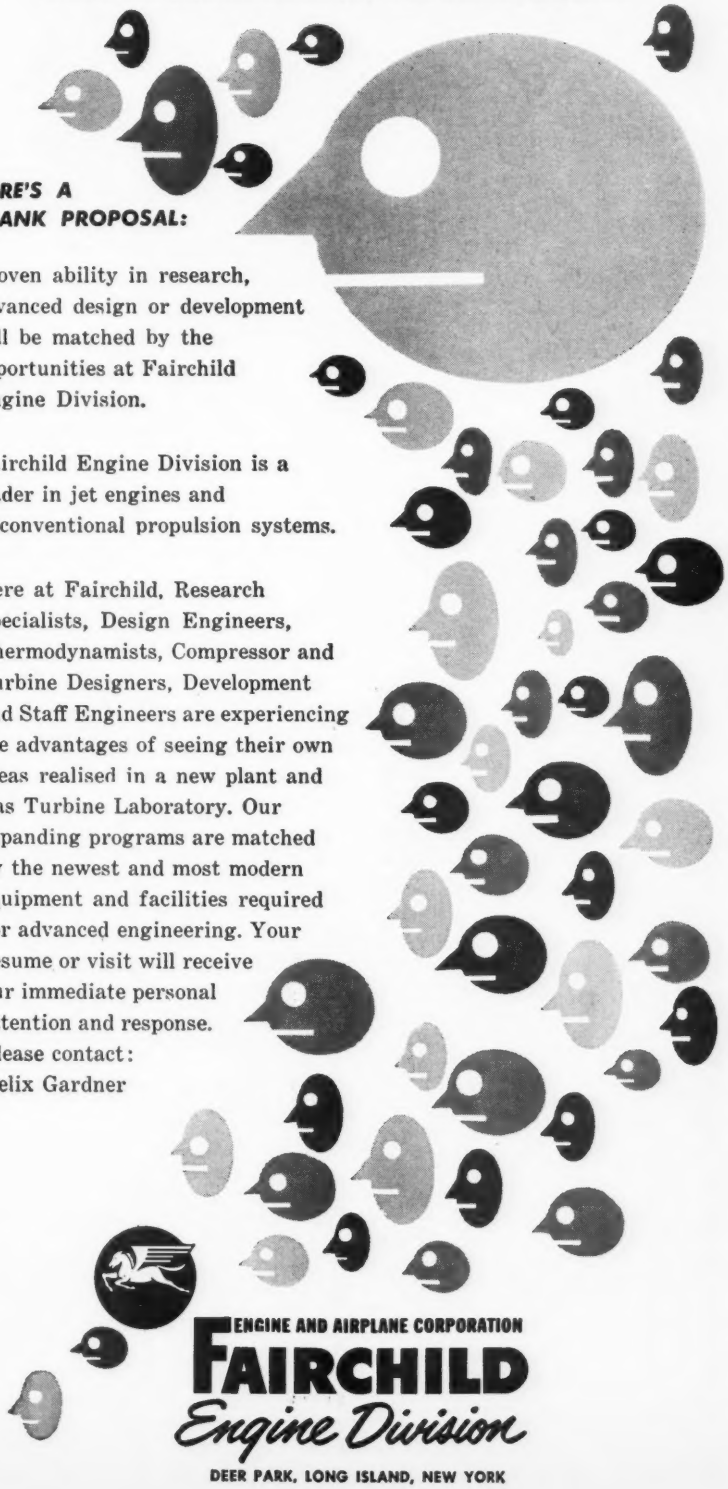

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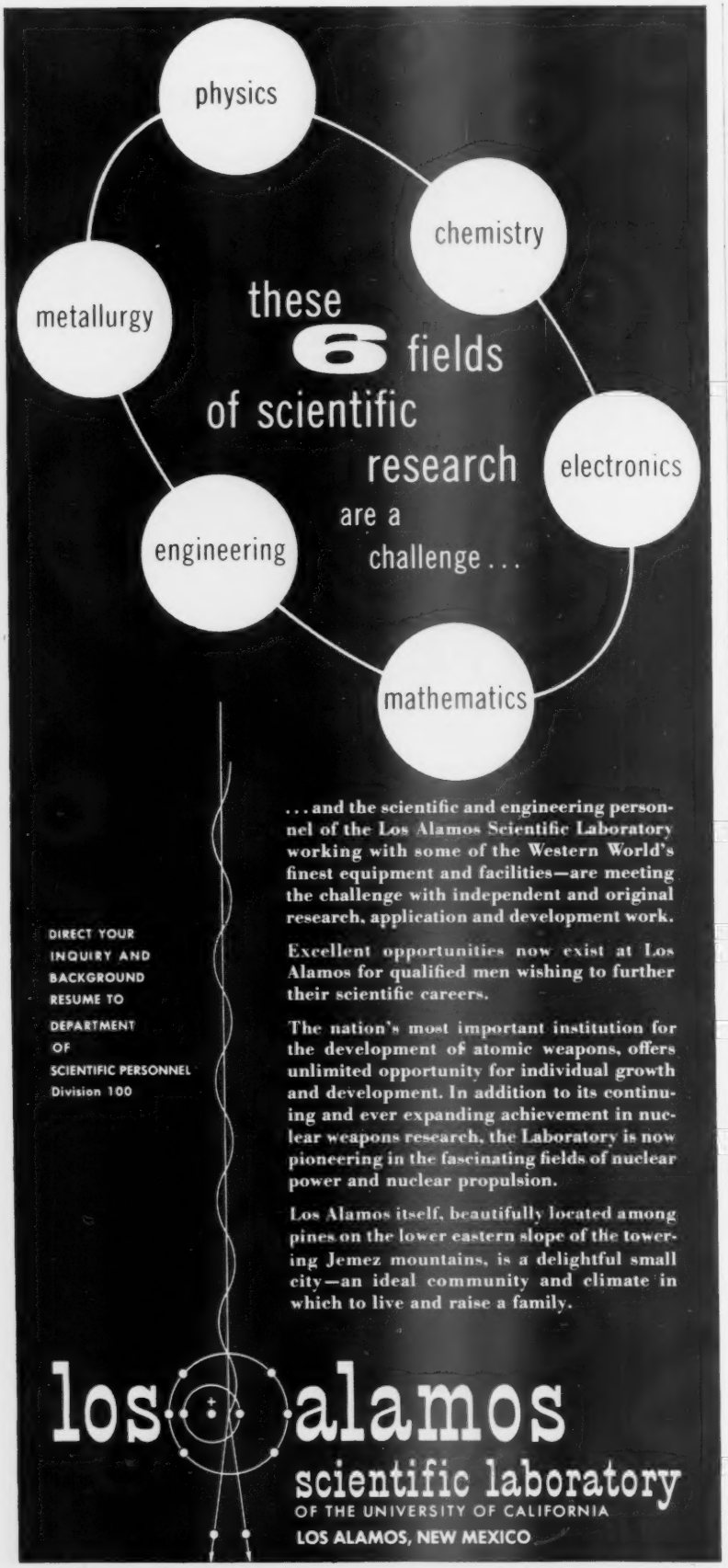
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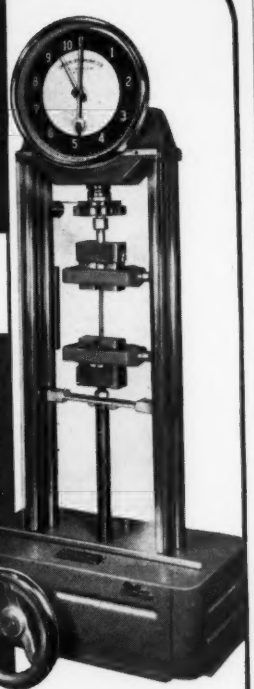

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Strenge Lösung für den durch zwei Einzelkräfte belasteten Kreisring. Robert Kappus. *ZAMM*, June–July, 1955, pp. 210–231. In German. Investigation applying the Muskhelishvili and Fourier methods of the problem of a circular ring subjected to loadings at the inner and outer edges by two isolated forces.

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Fatigue Life of Airplane Structures. (The Eighteenth Wright Brothers Lecture). Bo Lundberg. **Appendix A—Analysis of Damage Intensity and Cumulative Damage.** Sigge Eggwertz. (*J. Aero. Sci.*, June, 1955, pp. 349–413.) *Sweden, Flygtekniska Försöksanstalten, FFA Medd. 60*, 1955. 125 pp.; Discussion, 26 pp. 65 refs. Evaluative survey of prime aspects of the fatigue problem affecting complete structures of the fixed-wing transport variety, with emphasis on design techniques, operational and safety factors; development of a general formula for the calculation of cumulative damage basic to the determination of fatigue life within probability limits.

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Stress Analysis of Multi-Web Boxes. W. S. Hemp. *IAS-RAeS Fifth Internatl. Aero. Conf., Los Angeles, June 20–24, 1955, Preprint 556.* 22 pp. Members, $0.65; nonmembers, $1.00. Application of the analytical results for the ideal case of a cantilever box of uniform rectangular section having a single rigid rib at the tip receiving the external forces to the problems of a multiweb wing structure.

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The Intermittent Wind Tunnel. R. E. Street. *Trend in Eng.*, July, 1955, pp. 17–20. Descriptive appraisal of design, operation, experimental apparatus and techniques, and potentialities of the 3 × 3-in. tunnel at the U. of Wash.

Methode zur Bestimmung von Dämpfungsgrössen in Transonic- und Überschallkanälen. Fritz Lüscher. *ZAMP*, May 25, 1955, pp. 243–247. In German. "Rotor" method to determine damping values of models in transonic and supersonic tunnels, with measurements of the frequencies of oscillation as a function of time.

Some Results of the Princeton University Smoke Flow Visualization Program. David C. Hazen. *IAS-RAeS Fifth Internatl. Aero. Conf., Los Angeles, June 20–24, 1955, Preprint 555.* 19 pp. Members, $0.50; nonmembers, $0.85.

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Aeronautical Reviews — BOOKS

Book Notes

AERODYNAMICS

Technical Aerodynamics. Karl D. Wood. 3rd Ed. Ann Arbor, Mich., Published by the Author and Distributed by Ulrich's Book Store, 1955. 504 pp., illus., diagrs., figs.

The object of the edition, like that of the two preceding editions, is to provide a course of study for the engineering student (or a refresher course for the practicing engineer) which will help fit him to make the performance, stability, and aerodynamic design calculations of current importance in the aircraft manufacturing industry. This third edition reduces the attention paid to light airplanes and seaplanes and increases the attention paid to jet-propelled airplanes, jet-propelled missiles, and helicopters and helicopter-airplane combinations. With the increased scope of technical aerodynamic effort since the last edition (1947), the scope of fundamental principles involved and basic aerodynamic data necessary is also increased (in spite of omissions now permissible).

Osnovy Eksperimental'noi Aerodinamiki (Foundations of Experimental Aerodynamics). N. A. Zaks. Moscow, Oborongiz, 1953. 371 pp., illus., diagrs., figs. In Russian.

This book was written to fill the needs of a program that was established in the U.S.S.R. for the training of advanced aviation students on the college or university level. It is the outgrowth of a series of lectures given by the author which were prepared for the press in 1946 and published in 1948. The developments in experimental aerodynamics since the end of World War II, particularly in high-speed flight, led the author to make a thorough revision of the first edition.

In the present edition, some topics are considered, most of which were either lacking entirely or were only referred to briefly in the first edition. Among these topics are: low drag airfoils with an extended laminar boundary layer region; methods of aerodynamic investigation at high velocities of flow; the measurement of pressure, velocity, and Mach Number at high subsonic and at supersonic velocities; airfoil aerodynamic characteristics at subsonic, transonic, and supersonic velocities; the frontal drag of streamlined bodies of revolution at subsonic and supersonic velocities; and swept and low aspect ratio wings. New features in this edition are (a) those chapters which treat of the aerodynamic load distribution along the span of trapezoidal wings, wings with twist, and wings with deflected split flaps and (b) the calculation of the maximum lift coefficient of a wing without a landing flap and of a wing with a deflected landing flap.

There are also chapters on aerodynamic coefficients and aerodynamic similarity; test equipment and procedures; boundary layer and turbulence; the influence of geometric parameters and Reynolds' Number on the aerodynamic characteristics of airfoils and wings; the influence of compressibility; the drag of various shapes and components; and the aerodynamic characteristics pertaining to aircraft stability and control. The list of literature sources is brief and refers to only seven Soviet books published between 1925 and 1952 and one Czechoslovakian text published in 1949; however, it is stated that use was made of CAHI publications and of periodicals published in the Soviet Union and abroad.

Tekhnicheskaia Gasodinamika; Osnovy Gazodinamiki Turbin (Technical Gas Dynamics; The Fundamentals of the Gas Dynamics of Turbines). M. E. Deich. Moscow, Gosenergoizdat, 1953. 544 pp., illus., diagrs., figs. In Russian.

In the present book are presented some basic gas dynamic problems of the working section of turbomachines, in particular of stationary steam and gas turbines. It is based on lectures given by the author at the Molotov Energetics Institute in Moscow. In the first four chapters are presented the foundations of the theory of one-dimensional and plane flows of gas. In Chapters 1 and 2 the author considers in brief fashion the elements of the theory of motion of an ideal compressible fluid—the so-called isoentropic flows. Chapters 3 and 4 are devoted to some problems of the irreversible adiabatic processes of the motion of a gas—without energy exchange from the surrounding medium. Chapters 5 to 8 treat the special problems of the gas dynamics of the working part of turbines. Chapters 5 and 6 present the methods of calculating nozzles, diffusers, labyrinth constrictions, and ejectors. In Chapters 7 and 8 are considered the results of an experimental investigation on turbine buckets and also some fundamental questions of the theory of buckets and the turbine stage as a whole. The final chapter presents methods for the experimental investigation of the working part of turbines. The book presents the result of investigations conducted by Soviet scientists including the author and his associates. A bibliography of 65 references has been included which refers almost entirely to Soviet work.

AEROELASTICITY

Kolebaniia (Vibrations). B. V. Bulgakov. Moscow, Gostekhizdat, 1954. 891 pp., figs. In Russian.

The present work is divided into three parts, the first two of which were previously published in 1949. The third part is being issued for the first time, having been completed after the death in 1952, of the author, who was Professor and Chairman of the Mechanico-Mathematical Faculty, Moscow State University. The first part of the books contains fundamentals of matrix and operational calculus and an exposition of some questions of analytic mechanics which are more closely connected with the theory of vibrations.

In the second part are considered free and forced vibrations of systems with one degree of freedom which are chiefly nonlinear. In the first two chapters of Part 3 (chapters 7 and 8) are considered natural and forced vibrations of linear systems with many degrees of freedom. Together with a detailed and original exposition of the general theory, much attention has been paid to applications, in particular to the velocity of damping of vibrations, the accumulation disturbances under arbitrarily varying internal forces, and the theory of electrical networks. Chapter 9 is devoted to passive systems—that is, systems which do not contain energy sources. Chapter 10 is devoted to linear regulated systems. In Chapter 11 is considered the theory of linear systems with periodic coefficients.

Chapter 12 contains the theory of vibrations of nonlinear systems with many degrees of freedom. The appendix is a translation from a book by the author which was published in 1940. The 231 references listed at the end of the book are mainly to Russian sources.

AIRPLANES

The Jet Aircraft of the World. William Green and Roy Cross. Garden City, N.Y., Hanover House, 1955. 176 pp., illus., diagrs. $6.95.

This comprehensive book on jet aircraft and the history of propulsion contains over 600 photographs and almost 200 three-view identification silhouettes. There are hundreds of jet aircraft from all parts of the world covered in this volume, including many Russian models. Each is arranged in chronological order to show the step-by-step evolution of today's supersonic research, combat planes, and commerical jet aircraft. For each major type, whenever possible, there is a photograph of the actual plane, a three-view identification silhouette, a brief history of development, plus all available data on specifications, performance (some estimated), and armament. *The Jet Aircraft of the World* includes sections devoted to the various forms of jet propulsion, jet helicopters, and jet-engine test beds. These informative sections combined with a detailed index provide for all those interested in aviation an extremely valuable reference guide on jet propulsion.

ATOMIC ENERGY

Principles of Nuclear Reactor Engineering. Samuel Glasstone, with the Assistance of Staff Members of the Oak Ridge National Laboratory. New York, D. Van Nostrand Company, Inc., 1955. 861 pp., illus., diagrs., figs. $7.95.

The field of nuclear reactor engineering encompasses the design, construction, and operation of reactors for the release of energy in a continuous and controlled manner by the fission of certain atomic nuclei. The main purpose of this book is to describe the fundamental scientific principles

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upon which reactor engineering is based. Actually, the principles are not very complicated and are, on the whole, well understood, but in their translation into practice there are encountered various problems of a somewhat novel character due to the peculiar nature of the fission process and its associated radiations. Reactor engineering is largely concerned with the solution of these problems, involving a cooperative effort in which chemical, electrical, electronic, mechanical, and other engineers must work with chemists, mathematicians, metallurgists, physicists, and even biologists.

It is in order to facilitate such cooperation that this book covers a wide range of topics. The objective is to provide an overall review which will help the individual engineer to understand the relationship of his activities to that of the group as a whole. It should be emphasized that the subject of nuclear reactor engineering is treated in breadth rather than in depth. Nearly every chapter is, therefore, to be regarded as an introduction to a particular aspect of reactor design.

Two classes of reader, in particular, have been kept in mind in the preparation of this book. One is the practicing engineer who wishes to know something of the impact of nuclear energy upon his professional activities. For such a reader the book should serve as a guide; the inclusion of many cross references and reasonably complete index should help him find his way through the book even if he does not wish to read it systematically. The other class of reader is represented by students in engineering schools for whom it offers a broad view of the chemistry and physics, as well as the engineering principles of the nuclear reactor system. The author is Consultant, U.S. Atomic Energy Commission.

ELECTRONICS

Proceedings of the Symposium on Printed Circuits; University of Pennsylvania, Philadelphia, January 20-21, 1955. Sponsored by the Engineering Department, RETMA, and with participation of the Professional Group on Production Techniques, IRE. New York, Engineering Publishers, P.O. Box 1511, GPO, 1955. 122 pp., illus., diagrs., figs. $5.00.

This volume contains the 30 addresses delivered at the Symposium. Six sessions were held on the following broad topics: Product Design Application; Reliability and Serviceability; Management Considerations; Techniques of Producing Printed Wiring Boards; Printed Components and Components for Use with Printed Wiring; Production Techniques and Manufacturing Methods.

FLIGHT SAFETY

Design for Safety. Design Notes Prepared by William L. Lewis. New York, Published by *Aviation Age* with the cooperation of the Cornell-Guggenheim Aviation Safety Center, 1955. 48 pp., illus., diagrs., figs. $1.00.

This pocket-size booklet contains 36 illustrated design notes and ten human engineering bulletins that emphasize errors to be avoided for safe design of components and installations. It is considered to be an important supplement to the manuals and specifications used by designers and engineers. The illustrated material is in nontechnical form and can be understood readily by students, draftsmen, and maintenance and operations personnel.

RESEARCH

Proceedings of the Fourth AGARD General Assembly, Scheveningen, The Netherlands, May 3-7, 1954. Delft, Printed for the Netherlands Government by W. D. Meinema Ltd.; 1955. 160 pp., illus., diagrs., figs. United States Distribution by NACA, Washington, D.C.

This volume contains the addresses and general lectures presented to the Assembly. The technical papers given were as follows:

Human Factors in Aircraft Design, M. G. Whillans. Test Pilots' Round Table Discus-

sion: Subjective Experiences and Reactions during Flight Testing in the Transonic Region, R. Carpentier, W. J. Potocki, N. Duke, C. Yeager, Scott Crossfield. Low Temperature Operation of Aircraft, R. M. Aldwinckle. The Use of Personal Equipment in Arctic Survival, F. Vogt Lorentzen. Some Problems in Canadian Aeronautical Research and Development, D. C. MacPhail. Some Aspects of the Light Interceptor Problem, S. Stefanutti. Selected Aerodynamics Problems of High Speed Flight, K. E. van Every. Laminarization through Boundary Layer Control, C. V. Lachmann. Airworthiness Requirements, L. Lazzarino. Some Aspects of Aeronautical Research, P. Duwez. Airborne Electronic Equipment, M. Desirant. Some Studies of Laboratory Management, H. A. Shepard.

STRUCTURES

Bibliography on the Fatigue of Materials, Components, and Structures; Vol. 1, 1843–1938. Compiled by J. Y. Mann. Melbourne, Aeronautical Research Laboratories, Research and Development Branch, Australian Department of Supply, August, 1954. 288 pp.

This is the first of several volumes of a bibliography on fatigue which is being issued for the assistance of scholars, engineers, designers, and research workers. Because of the large number of references (2,119 are listed in Vol. 1), several volumes were decided upon; the references are given in order according to their year of publication and alphabetically in those years according to the name of the author or authors. No attempt was made to index or segregate the information according to subject matter, as it was felt that titles alone can be misleading and could result in the indexing of papers under incorrect subject headings. No author index is yet provided. This bibliography is based on one issued by the Australian CSIR in 1945 and has been supplemented by references which have appeared in standard indexing and abstracting publications and in other bibliographies on the subject which have appeared in various books and journals.

THERMODYNAMICS

Conduction Heat Transfer. P. J. Schneider. Cambridge, Mass., Addison-Wesley Publishing Company, Inc., 1955. 395 pp., illus., diagrs., figs. $12.50.

This text is designed for use in the first of a three-semester sequence of graduate level courses on conduction, convection, and radiation and for use as a supplementary text in the usual undergraduate course covering the three modes of heat transfer in one semester. Four methods of evaluating temperature fields are considered: analytical, graphical, numerical, and experimental. The reader is expected to have only the usual undergraduate background in the calculus and ordinary differential equations and little or no acquaintance with the properties and integration of partial-differential equations. The author is Research Associate, Department of Mechanical Engineering, University of Minnesota.

Contents: (1) Introduction. (2) Steady One-Dimensional Systems. (3) Differential Equations of Bessel and Legendre. (4) Extended Surface. (5) Fourier Series and Integration of Partial-Differential Equations. (6) Steady Two-Dimensional Systems. (7) Steady-State Numerical Method. (8) Steady Heat-Source Systems. (9) Steady Porous Systems. (10) Transient Systems; Heating and Cooling. (11) Transient Systems; Unsteady Boundary Conditions, Stationary and Moving Sources. (12) Transient Numerical Method. (13) Experimental Analogic Method. Appendix: Computation Tables. Index.

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YEARBOOKS

Aircraft Engines of the World, 1955. Paul H. Wilkinson. New York, The Author, 225 Varick Street, 1955. 320 pp., illus. $12.

As in previous editions, the emphasis is on aircraft gas turbines, both turbojets and turboprops, although there are quite a number of new reciprocating engines. Rocket-jet data have been increased, and specialized power plants occupy considerably more pages than before. Much of the information about the accessories and equipment is new, as are the data in the tabulations of aircraft and their power plants, which now include guided missiles. The two introductions review the progress made by different manufacturers in various countries, with an overall summary with respect to types. Many photographs are new, and the contents are revised to May, 1955.

The Aircraft Year Book, 1954. Official Publication of the Aircraft Industries Association of America, Inc. Editors: Fred Hamlin, Eleanor Thayer, and Lynn Black. Washington, Lincoln Press, Inc., 1955. 472 pp., illus., diagrs. $6.00.

Following the format of previous editions, the 1954 volume includes: aircraft in production during 1954 described in detail with photographs and three-view drawings; aviation chronology up to the end of 1954; biographical notes of over 1,200 aviation personalities; review of latest developments in guided missiles; current aviation records and statistics.

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